Judicious Application of Satellite Observations To Evaluate And Improve Cloud Ice and Liquid Water Representations In Conventional and Multi-Scale Weather & Climate Models

PI: Duane Waliser/JPL,
Co-Is : Frank Li/JPL, Joao Teixeira/JPL
Collaborators: J. Bacmeister/GSFC, J. Chern/GSFC, A. Del Genio/GISS,
R. Forbes/ ECMWF, Z. Kuang/Harvard, G. Stephens/CSU, W.K. Tao/GSFC

Summary

Present-day shortcomings in the representation of clouds in general circulation models (GCMs) lead to errors in weather and climate forecasts as well as account for a principal source of uncertainty in climate change projections. An ongoing challenge in rectifying these shortcomings has been the availability of adequate, high-quality, global observations targeting clouds and related precipitating hydrometeors. In addition, the inadequacy of the modeled physics and the often-disjointed nature between model representation and the characteristics of the observed values have hampered GCM development and validation efforts from making effective use of the observations that have been available. Thus, even though parameterizations in GCMs accounting for cloud ice and liquid processes have, in some cases, become more sophisticated in recent years, this development has largely occurred independently of the global-scale observations. This has led to serious deficiencies in the representation of cumulus convection and associated cirrus anvils, mid—level cumulus congestus, stratocumulus, and boundary-layer stratus clouds. These deficiencies range from the considerable uncertainties in their modeled radiative feedbacks in conjunction with climate change *to the most basic properties such as representing their liquid and water contents correct to within an order of magnitude.* With the relatively recent addition of satellite-derived products from CloudSat, CALIPSO, Aura/MLS, etc., along with longer running products from MODIS and CERES, there are now considerably more resources with new and unique capabilities to evaluate and improve cloud representations in GCMs.

In this proposal, we will develop judicious approaches for making model-data evaluations and use these evaluations to improve cloud-related parameterizations in conventional and Multi-Scale GCMs. This includes accounting for sensor sensitivities and algorithm assumptions and the spatial/temporal sampling constraints of the instruments, as well as accounting for the physical assumptions in the model's parameterized hydrometeor representation. Specific processes/parameterizations to be addressed include extensions of our ongoing work with upper-tropospheric ice clouds and analogous studies on lower-tropospheric liquid clouds, primarily using CloudSat and MLS cloud-retrievals and available instrument simulators. These data will be augmented by AIRS and GPS temperature and moisture soundings, and ISCCP, MODIS/CERES, CALIPSO and SSMI/AMSR-E cloud-property characterizations. Specific models to be examined - with a focus on improving cloud ice and water content representation - include NASA GEOS5 and GISS GCMs, NASA fvMMF and Harvard DARE Multi-Scale GCMs, and the ECMWF and MERRA analyses. In addition, we will lead in the participation, on behalf of GEOS5, in two GEWEX cloud-modeling projects, the Cloud Feedback Model Intercomparison Project (CFMIP-2) and the Pacific Cross-section Intercomparison (GPCI) project. The outcome of this effort will be: I) the development of a number of robust and complementary methods for making model-data comparisons using the above satellite observations of clouds and related processes, II) quantitative evaluations of the representations of ice and liquid clouds in a number of contemporary GCMs and, III) through our own efforts and the close collaboration with the modeling teams, sorely needed improvements in our GCM representations of the mass, size distribution, and floating/falling characteristics of the liquid and frozen hydrometeors. These outcomes will demonstrate the value of the synergistic use of measurements from a number of contemporary satellites. It will also lead to more realistic treatments of cloud properties in our weather and climate prediction models, and in regards to the latter, has the potential to reduce the uncertainties in future suites of global change projections through improved cloud (feedback) representations.

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1 Scientific/Technical/Management

1.1 Scientific Issues

1.1.1 Background

The importance of obtaining a more comprehensive understanding and improved capability for modeling both upper-tropospheric ice as well as lower-tropospheric liquid clouds cannot be overstated as “cloud feedbacks remain the largest source of uncertainty” in determining Earth’s equilibrium climate sensitivity, specifically to a doubling of carbon dioxide [*IPCC*, 2007]. Some evidence for this uncertainty is given in **Figure 1** that shows model-to-model comparisons of five different physical climate quantities, including cloud ice and liquid water path (IWP & LWP; gm m^{-2}). While it is understood that models exhibit significant systematic spatial-temporal biases with respect to quantities such as precipitation, water vapor and clouds, their agreement in the globally-averaged values is quite good. This stems from the fact that these quantities have had relatively robust long-standing observational constraints [*Arkin and Ardanuy*, 1989; *Rossow and Schiffer*, 1991; *Stephens et al.*, 1994; *Xie and Arkin*, 1997] as well as indirect measurement constraints via top of the atmosphere radiation measurements [*Gruber and Krueger*, 1984; *Kyle et al.*, 1993; *Smith et al.*, 1993]. In contrast, robust global (or globally representative in-situ) observations of cloud ice, particularly vertically-resolved values, have not been available. Despite significant efforts to derive even cloud water *path* from passive and nadir-viewing techniques, the large optical depths, multi-layer structure, and mixed-phase nature – including the presence of precipitating hydrometeors, of many clouds makes the estimates from these techniques very uncertain [*Stephens et al.*, 2002; *Wu et al.*, 2006; *Horváth and Davies*, 2007]. The ramifications of this poor constraint for cloud water mass, even in total water, are evident in the much larger model disagreement for globally-averaged cloud ice and liquid paths shown in **Figure 1**. Even when the largest outliers are removed, there is still a factor of over 5 between the largest and smallest values. As expected, these differences are exacerbated when considering the spatial patterns of the time-mean values shown in ***Figure 2*** *(IWP exhibits very similar model patterns/disagreement)*; in some regions up to nearly *two orders* of magnitude. For quantities as fundamental and – in principle - relatively unambiguous as cloud ice and liquid water mass, one that also has significant import within the context of climate change and its associated model projection uncertainties, it is critical that this model uncertainty be reduced.

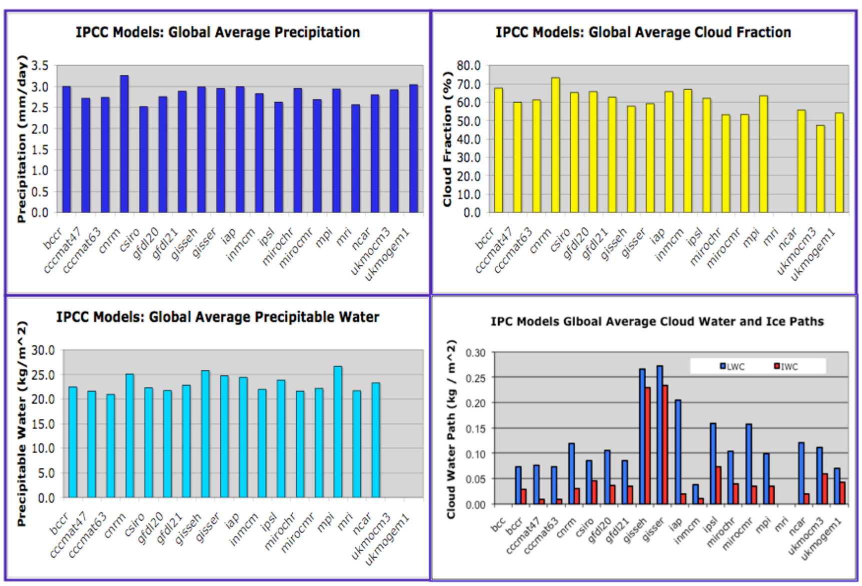


Figure 1*. Globally-averaged, annual means of precipitation, precipitable water, cloud fraction and cloud IWP & LWP from the 1970-94 period of the 20th century GCM simulations contributed to the IPCC FAR (20c3m scenario). Zero values indicate that the given model did not provide this variable to the IPCC (i.e. CMIP3) database.*

Fortunately, there are new observational resources recently established that can be expected to lead to considerable reduction in the uncertainties associated with model representations of cloud water and ice. Specifically, these include the Microwave Limb Sounder (MLS) on the Earth Observing System (EOS) Aura satellite, and the CloudSat and CALIPSO satellite missions, all of which fly in formation in what is referred to as the A-Train [*Stephens et al.*, 2002]. Based on radar and limb-sounding techniques, these new satellite measurements provide a considerable leap forward in the information gathered regarding tropospheric cloud water content as well as other macrophysical and microphysical properties [e.g., *Waliser et al.*, 2007; *Wu et al.*, 2007]. – in particular vertical structure (e.g., ice and liquid water content, IWC and LWC, respectively; mg m^{-3}).

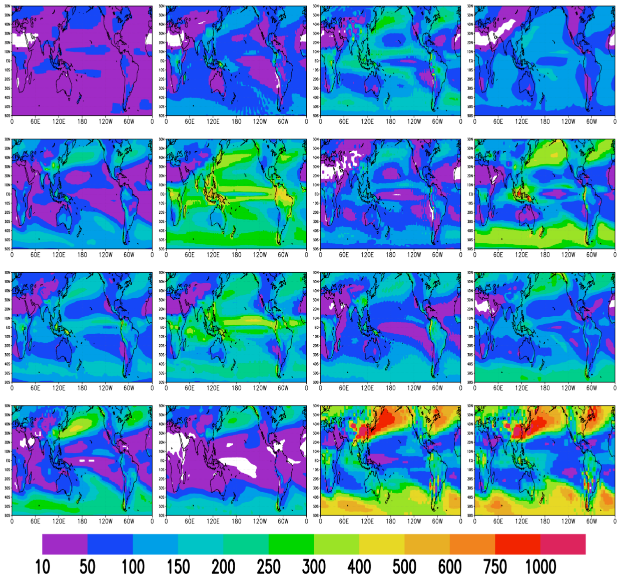


Figure 2. Annual mean values of cloud LWP (gm m^{-2}) from 1970-94 of the 20th century GCM simulations contributed to the IPCC FAR (20c3m scenario); <u>Note the color scale is not linear and IWP exhibits similar model disagreement.</u>

In our proposed research, we will judiciously apply state-of-the-rt cloud-related measurements from the EOS/A-Train and complementary satellites in order to diagnose the shortcomings in, and in turn work to improve, the representation of clouds in contemporary weather and climate models. The specific objectives are given in Section 1.2, with the methodology and proposed research plans described in Section 1.3. <u>Addressing these objectives will contribute to NASA's Strategic Goal 3, "Develop a balanced overall program of science, exploration, ... focus on exploration", and specifically to Strategic Subgoal 3A, "Study Earth from space to advance scientific understanding and meet societal needs.</u>" More discussion of the relevance and expected outcomes is given in Section 1.4.

It is worth noting at this time that for both IWP and IWC, and for both the satellite retrievals and the models, it tends to be understood that "ice" represents all frozen hydrometeors, and can include "cloud" ice – which is typically suspended (or very slowly falling), and ice mass in precipitating forms such as snow and graupel. Similarly for LWP and LWC, considering both cloud droplets and rain. However, such distinctions are often not clearly made or are fuzzy, and certainly not always made consistently between the satellite retrievals, the model parameterizations and/or what is output from the models. A principle focus of our activities is to consider such distinctions with care in conducting the proposed model evaluation, diagnosis and development research.

1.1.2 Satellite Observations

In this subsection, we briefly describe a subset of the satellite observations relevant to this work, with a demonstrative (due to length limitations) focus on CloudSat retrievals of ice and liquid water content. The left half of **Figure 3** illustrates a number of products developed to estimate IWP. This includes three products based on passive detection of infrared and visible radiation, CERES/MODIS [*Minnis et al.*, 1995; *Minnis et al.*, 1998; *Wielicki et al.*, 1998; *Minnis and al.*, 2007], MODIS [*Platnick et al.*, 2003] and ISCCP [*Rossow and Garder*, 1993; *Lin and Rossow*, 1996; *Jin and Rossow*, 1997; *Han et al.*, 1999; *Rossow and Schiffer*, 1999]. While these products exhibit considerably better agreement than the models shown in **Figure 2**, there is still a fair bit of discrepancy, particularly over land and high latitudes. Part of this derives from the fact that multi-level, mixed-phase and thick clouds represent a significant challenge for passive IR/visible techniques, as do variable and bright surface conditions. While a passive microwave product is also available [*Zhao and Weng*, 2002; *Ferraro et al.*, 2005], it exhibits considerable disagreement from all the products shown in **Figure 3** in large part because the sensor/wavelengths are not sensitive to particles less than 0.4 mm in diameter.

It is beyond the scope of this presentation to describe the details of each of these algorithms but as an illustrative example of the types of steps and assumptions involved, we briefly describe the CERES/MODIS retrievals (see refs above). First, each 1-km cloudy MODIS pixel is classified as ice or water based on the cloud temperature and the goodness of the match between the observed spectral radiances at three wavelengths and model calculations of the radiances using several different ice and water particle size assumptions. With the entire column assumed to be ice, IWP is computed as a function of the product of the retrieved effective ice crystal size and optical depth for each pixel (limited to <= 128 in the current edition). Although good agreement is found between ground-based cloud radar and the CERES retrievals of IWP for relatively thin cirrus clouds (optical depths < 4) with no underlying water clouds [*Mace et al.*, 2005], *validation of IWP for thick clouds has not yet been performed, primarily due to a lack of reference data*. As mentioned above, the impact of multi-layered clouds on such passive IWP retrievals is significant. *Huang et al.* [2006] and *Minnis et al.* [2007] showed that the assumption of the entire cloud column as ice leads to overestimates in IWP of roughly 50% in multi-layered systems. Thus, if one assumes that half of all ice clouds overlap liquid clouds, then global estimates of IWP from passive visible, infrared, and near-infrared measurements are likely to be overestimated by around 25%. The data illustrated in **Figure 3** use averages of IWP derived using Terra MODIS data taken for solar zenith angles less than 82°. The means are multiplied by the average ice cloud fraction for each region to obtain all-sky values. This brief discussion of one of these passive techniques indicates the types of assumptions/determinations (e.g., cloud-masking, cloud phase, habit and size, column characteristics, choice of channels, overall level of uncertainty) that need to be considered in making use of the data for model comparisons.

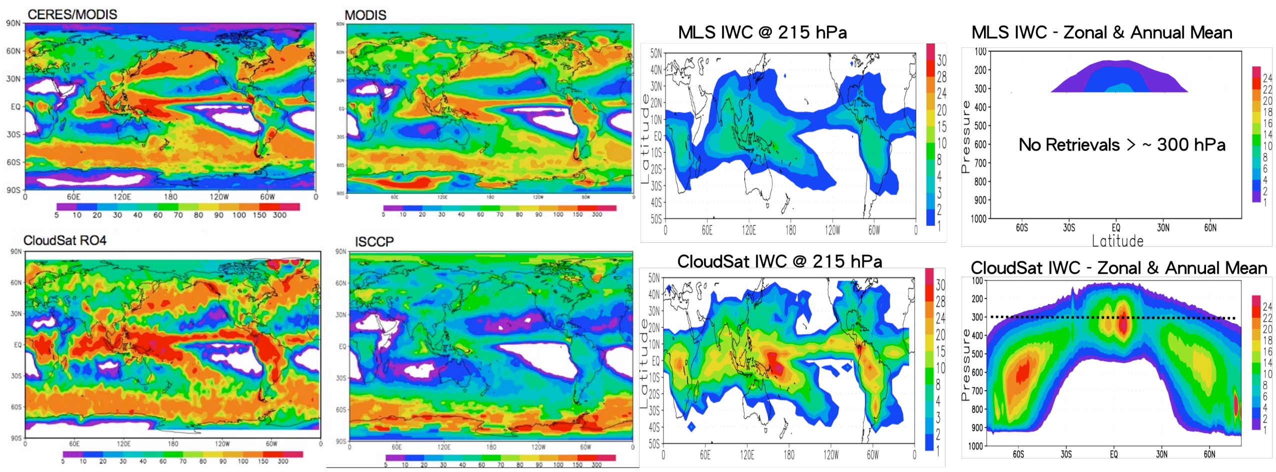


Figure 3. LEFT HALF: *Annual mean values of (all-sky) cloud ice water path (IWP; gm m*$^{-2}$*) from CERES/MODIS (upper left; 2001-2005), MODIS MYD06 (upper right; 7/2002-6/2007), CloudSat (lower left; 8/2006-7/2007), and ISCCP (lower right; 2005).* ***RIGHT HALF:*** *Annual mean values of cloud ice water content (IWC) at 215 hPa (left) and zonal average (right) from MLS (upper; 8/2004-7/2007) and CloudSat (lower; 8/2006-7/2007). For upper right panel, MLS retrievals only extend down to 316 hPa.*

Of great importance for the work associated with this proposal is the vertical structure information provided by both the radar and limb sounding capabilities of CloudSat and MLS, respectively; each provides estimates of IWC with MLS observations limited to the upper troposphere. Due to length limitations, we will only highlight CloudSat's methodology, and discuss the relevant issues for the limb-sounding MLS below; detailed discussions on MLS can be found in Wu et al. [2006; 2007]. The Cloud Profiling Radar (CPR) on the CloudSat satellite (since 6/2006) is a 94 GHz, nadir-viewing radar measuring backscattered power from the Earth's surface and particles in the atmosphere [*Stephens et al.*, 2002]. Measurements of backscatter are converted to calibrated geophysical quantities (radar reflectivity), which are then used in retrievals of cloud and precipitation properties, such as IWC and LWC. Because the CPR does not scan, measurements consist of profiles along the satellite ground track, providing a vertical cross section of clouds, with a footprint of ~1.5 km. The minimum detectable reflectivity is ~ -30 dBZ. The current CloudSat retrieval for ice water content (IWC) (v5.1, in release 4 [R04] of the 2B-CWC-RO product) uses an optimal estimation approach to retrieve parameters of the ice particle size distribution (PSDs) based on measurements of radar reflectivity [*Austin et al.*, 2008]. A priori data constructed from a database of cloud microphysical measurements constrain the solution where the measurements cannot; the a priori data values are selected as a function of temperature, via ECMWF analyses. The retrieval assumes a lognormal size distribution of cloud particles, retrieving the distribution's three parameters *(which are also reported and used below)* for each radar bin and calculates IWC and other quantities from the retrieved parameters. A similar retrieval is performed for liquid water content (LWC); the composite profile contained in the 2B-CWC-RO product is obtained by using the LWC (IWC) retrieval for bins warmer (colder) than 0°C (-20°C), *and a linear combination of the two in the intermediate temperature range.* (see **Figure 11)**The minimum detectable IWC is estimated to be ~5 mg m^{-3}, depending on the distribution parameters. The annual mean IWP estimate from CloudSat is shown in **Figure 3**, along with CloudSat's estimate of annual mean IWC at 215 hPa and the zonal average – with MLS values also shown for comparison. While the IWC retrieval does not consider larger species such as snow and graupel explicitly, the radar is certainly sensitive to larger particles due to the powerful dependence of radar reflectivity on particle size (D^6 for Rayleigh regime, but less as particles move to the Mie scattering regime). Efforts are underway to determine the accuracy of the retrieved IWC values in the presence of larger particles [e.g., *Woods et al.*, 2008].

Overall, the brief discussion above is meant to convey three messages. The first is that, until recently, the availability of *global* cloud ice estimates was limited to IWP based on passive infrared or microwave techniques (e.g., NOAA, CERES, MODIS, ISCCP). These products' known limitations and uncertainties, including their limited intercomparison and validation, have hampered their use in constraining modeled cloud ice values. The second is that more recent strategies (e.g., limb-sounding and radar) are better equipped to probe and characterize internal cloud properties, such as profiles of IWC. However, at first glance there appears to be considerable disagreement between the two new (MLS & CloudSat) estimates of "cloud" IWC as well as disagreement between CloudSat IWP and those based on passive techniques. This raises the third message, that considerable caution must be applied when using them for model evaluation and development. For example, CloudSat is thought to be sensitive to nearly all the frozen hydrometeors in the column, and have a sensitivity of about 5 to 200 or more (mg m^{-3}), while MLS has a sensitivity of about 1 to 50 mg/m^3. Analogous considerations such as those above apply to cloud liquid water retrievals. Due to space limitations these will not be discussed, however **Figure 4** illustrates LWP and LWC retrievals for comparison.

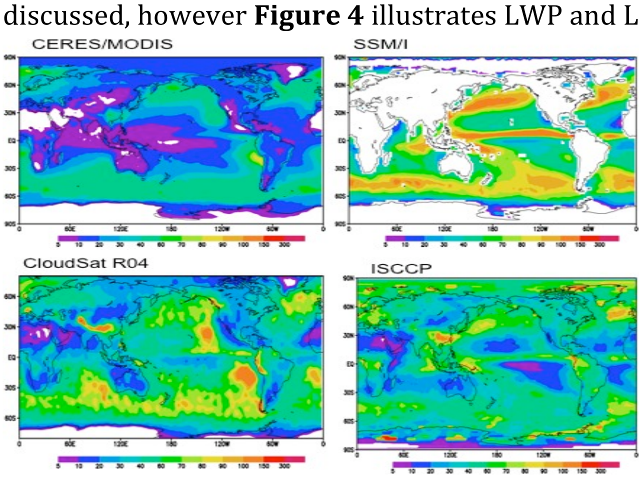
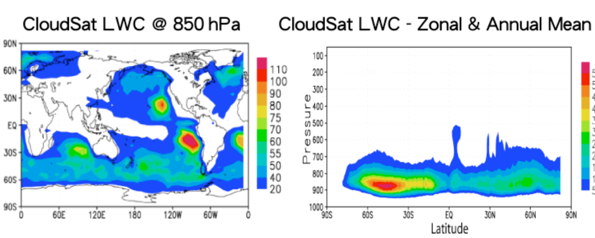


***Figure 4. LEFT HALF:** Same as Figure 3, except for LWP (gm m^{-2}), and with SSM/I instead of MODIS in upper right. **RIGHT HALF:** Annual mean values of cloud IWC at 850 hPa (left) and*



1.1.3 Model Representations

In this subsection, we briefly describe the considerations typically in place within a GCM that account for the simulation of frozen hydrometeors in the atmosphere – both cloud ice and precipitating frozen particles. *Analogous considerations are applicable to liquid water but due to length limitations, they will not be discussed here, except as relevant in Section 1.3.* In GCMs, atmospheric processes associated with convective clouds and non-convective clouds are artificially separated into cumulus convection and stratiform cloud schemes, with the cumulus parameterization typically based on a convective mass fluxes approach [*Arakawa and Schubert*, 1974; *Tiedtke*, 1989; *Gregory and Rowntree*, 1990; *Zhang and McFarlane*, 1995]. Important to note is that due to the observed small spatial scales of cumulus convection, the influence they have on cloudiness and thus radiation has often been neglected with the main objective only being their direct impact on humidity and temperature via latent heating. Due to the large spatial scales of stratiform clouds, GCMs have generally accounted for "cloudiness", and its effect on radiation, via this part of the model's parameterization.

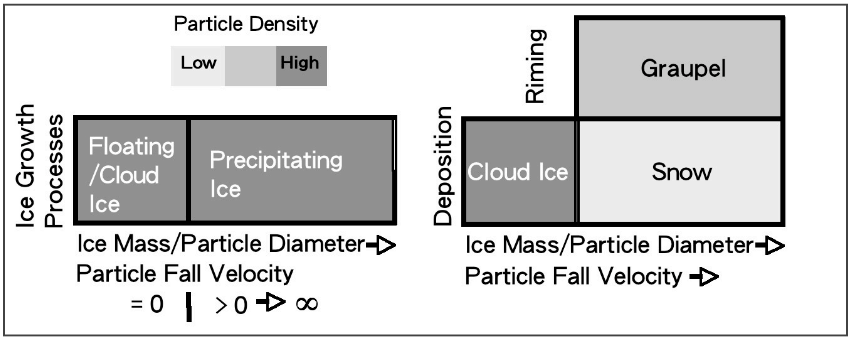


Figure 5. *Schematic diagram illustrating basic features of model parameterizations of cloud-related ice for a conventional GCM using a single species microphysics scheme (left) and a 3-species microphysics scheme (right).* The vertical axes are associated with ice growth processes and the horizontal axes are associated with ice mass and/or particle diameter and also particle fall velocity. On the left figure, ice growth processes are not distinguished and are all embedded within the simplified parameterization. On the right figure, deposition is the primary process associated with cloud and snow, while riming is the primary processes responsible for graupel formation. On the left figure, cloud ice is assumed to be floating, i.e. zero fall velocity, and the ice deemed to be precipitating is removed immediately, i.e. infinite fall velocity. Shading is an indication of the density of particles.

Studies have shown that non-convective stratiform clouds (e.g., precipitating anvil clouds and cirrus) can be produced by the detrainment from cumulus convection. Such connections within a modeling context have been made by coupling stratiform clouds and cumulus convection in GCMs [e.g., ***Tiedke***, 1993] by allowing convective detrainment to serve as a source of the large-scale cloud. In general, non-convective clouds and their condensates are formed, maintained and dissipated by many processes such as small-scale turbulence, large-scale vertical motion, convection and cloud microphysical processes. For example, for ice clouds, processes to be considered include: the formation (e.g., nucleation, deposition) and possible sedimentation, the growth and interactions (e.g, deposition and riming, aggregation), precipitation, the evaporation/sublimation of both clouds and precipitation, and possibly advection of clouds and precipitation. Due to computational considerations as well as our incomplete knowledge, most GCMs utilize fairly simple cloud schemes.

Figure 5 is a highly simplified schematic illustrating the most rudimentary features and considerations in these representations. It mainly distinguishes the highly simplified forms in typical GCMs (e.g., **Figure 2)** used for global weather forecasting as well as many forms of climate simulation (left) versus a somewhat common next level of sophistication (right). In the former, there is consideration of only a single species of condensate, "floating" (or very slowly falling) cloud ice. Processes within the parameterization – relying on the large-scale fields – lead to the development and dissipation of the clouds. In some cases, the processes are treated empirically, and are implicit, in others they are more explicitly represented [*Jakob*, 2002], and in most recent parameterization schemes clouds are modeled prognostically [e.g., *Sundqvist*, 1978]. Important in this class of parameterizations is that a fraction of condensate is typically assumed to have grown to a mass/particle size large enough to be considered precipitation, and is assumed to immediately fall out – albeit it can moisten lower layers in the fall out process. *Highly relevant here is that depending on what the model considers "large enough" (or something physically similar), the model output for "cloud" IWC or IWP* (e.g., **Figure 2**) *can deviate simply based on this definition although the models may actually exhibit better good agreement when considering the total mass (floating plus falling; more on this in later sections).* In such cases, the GCM typically reports the cloud/floating ice – although in some cases (e.g., ECMWF, MERRA, GEOS5) the falling portion is quantified but not often included in standard output. In addition to the cloud ice mass, the model also typically reports horizontal cloud fraction. Such a formulation is also referred to as a single-moment scheme, because the number concentration of the ice particles is prescribed and only the mass is predicted. More complex formulations, common in regional and cloud-resolving models (CRMs), include double-moment schemes that also predict number concentrations, or even more computationally expensive spectral and bin microphysics that include multiple discrete particle sizes, number concentrations and particle-particle interactions.

Another level of complexity beyond the simplified single-species representation is allowing more ice condensate species (e.g., snow and graupel). A simplified representation of this is illustrated in the right side of

Figure 5. In this case, cloud ice is distinguished from snow and graupel by a consideration of particle size and/or the amount of overall ice mass, and graupel is distinguished from snow via the ice growth process during its formation (i.e. deposition or riming). In these cases, there is typically a prescribed particle density for each species. In addition, such schemes often take particle fall velocities into consideration, with even the cloud ice subject to sedimentation.

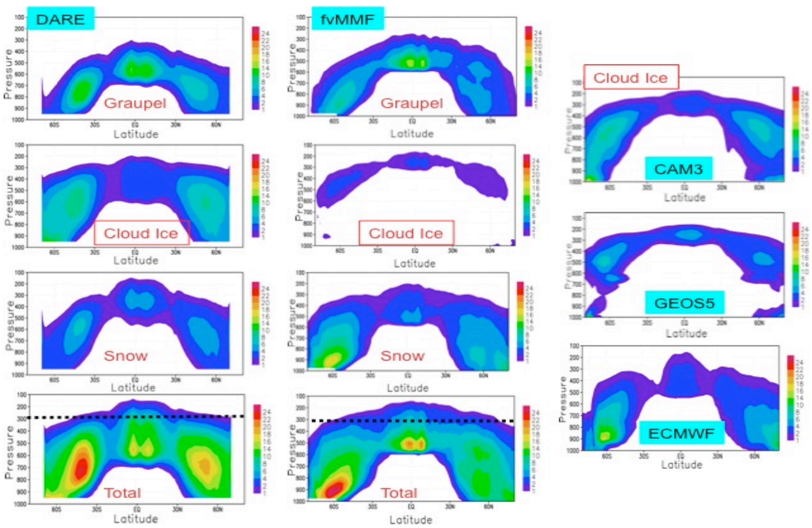


Figure 6. LEFT PORTION: *Annual and zonal mean values of graupel (upper), cloud ice (upper middle), snow (lower middle) and their sum (lower) from the RAVE (left) and NASA fvMMF (right) GCMs.* ***RIGHT PORTION:*** *Annual and zonal mean values of cloud ice water content (IWC; mg m^{-3}) from NCAR CAM3 (upper; 1979-1999), NASA GEOS5 (middle; 01/1999-12/2002), ECMWF R30 analysis (lower; 08/2005-07/2006).*

As a demonstration and model comparison of the types of quantities discussed above, **Figure 6** illustrates the atmospheric ice fields for the Harvard/DARE [*Kuang et al.*, 2005] and GSFC/fvMMF [*Tao et al.*, 2003; *Tao et al.*, 2006] multi-scale modeling framework (MMF; *While MMF has been typically reserved for GCMs incorporating a CRMs within each grid (i.e. super-parameterization), DARE is also an attempt to explicitly represent the convective and large-scale motions, and thus for this proposal will be also be referred to as an MMF.*) GCMs and the NCAR CAM3, NASA GEOS5 and ECMWF (analyses) GCMs. In the former, the models each include graupel, snow and cloud ice as separate species; also shown is their total. Evident is that of the total ice field within the column for each model, snow, graupel and cloud ice each makes sizeable contributions to the ice mass. Note that until recently, there have been virtually no global observations available to provide even a rudimentary form of validation for such a diagram, neither the mass of one of the species alone, the total modeled here by the MMFs, nor any of their vertical structures. Moreover, while there is relatively good agreement between the two MMFs in total ice, there is considerable disagreement for any given species – cloud ice in particular. Note that these differences may be somewhat immaterial and only arise due to the manner the two MMFs represent the ice water content of the different species. While the fvMMf and DARE employ similar microphysics based on Rutledge and Hobbs [1983; 1984] and Lin et al. [1983], differences exist in their implementation of these schemes. For example, snow and graupel particles are assumed to follow exponential distributions in both models, however the parameters defining the distribution in each are defined differently. Sensitivity studies of similar microphysical scheme parameters [e.g., *Woods et al.*, 2007] have demonstrated the relatively large impacts their values have on ice particle growth, precipitation and associated microphysical processes. Since the ice particles may be distributed differently, it would be advantageous to compare ice contents by species *and* size. A method to facilitate such comparisons is discussed in Section 1.3.

1.1.4 Model-Observation Comparisons

The last two sections highlighted the types of novel satellite data resources available to examine cloud-related liquid and ice characteristics (e.g., mass) and the manner these fields are represented in contemporary GCMs. From this discussion it is evident that direct comparison of the model and satellite-derived ice fields needs to be considered with caution. Based on the discussion, it is evident that CloudSat IWC values cannot be used to directly compare with GCM *cloud* IWC (e.g., the cloud ice values in **Figure 6**), since the former is sensitive to all the falling/frozen hydrometeors. In this case, it would be a more useful constraint for the total ice fields for example in the fvMMF and DARE models. In fact, comparing the IWC from CloudSat (lower right **Figure 3** or top **Figure 8**), suggests a relatively good order of magnitude agreement between CloudSat IWC versus the MMFs' total IWC values. One notable exception is the height of the IWC maximum in the tropics, the maxima in the models is considerably lower (~550 hPa) than that for CloudSat (~300 hPa). This could indicate a shortcoming in the circulation, the model microphysics – which either way would likely indicate a problem in relation to the latent heating distribution, or it could be associated with the manner the liquid-only and ice-only retrievals are combined. This issue will be discussed in more detail in Section 1.3.

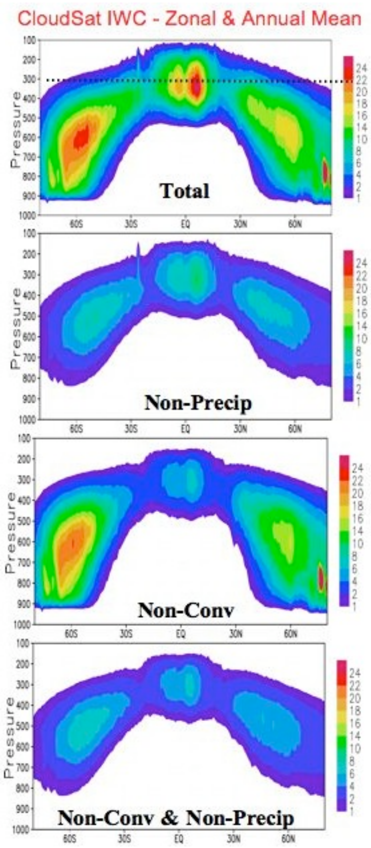


Figure 8. *Annual and zonal mean values of CloudSat IWC (mg m^{-3}) when considering clear cases and those with IWC > 0 but flagged as having no precipitation at the surface (NP; upper), cases flagged as non-convective clouds (NC; middle), and those cases that meet both these criteria (NP & NC; lower).*

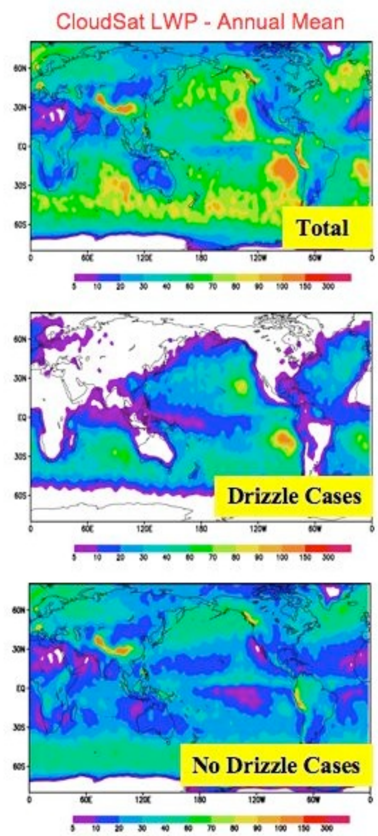


Figure 7. Annual and zonal mean values of CloudSat IWC (mg m^{-3}) when considering clear cases and those with IWC > 0 but flagged as having no precipitation at the surface (NP; upper), cases flagged as non-convective clouds (NC; middle), and those cases that meet both these criteria (NP & NC; lower).

Despite having a preliminary estimate of total IWC from CloudSat (i.e. top of **Figure 8**), it would still be valuable to have a form of validation for the *cloud* ice fields, that isn't contaminated with (or that doesn't include larger frozen precipitating hydrometeors). Our preliminary method for this is to use the cloud classification and surface precipitation flags that come with the CloudSat retrievals. **Figure 8** shows the CloudSat IWC field if only cases are included that are non-convective (NC), have no precipitation at the surface (NP), or both. This conditional sampling leaves out most cases with falling hydrometeors and thus can plausibly use this as an *estimate* of the IWC in just "clouds" and thus compare it to the second row or right column in **Figure 6** – for such comparisons the order of magnitude agreement is quite good**.** Keep in mind that an observed estimate accurate to within a factor of 2 would be a vast help when considering **Figure 2.** Section 1.3.5 shows, through the application of the CloudSat simulator, that this approach has some merit in selecting the intended cloud population. A similar consideration can be made regarding the impact of precipitation - in this case drizzle - on the CloudSat LWC field, with the impact of including or not including drizzle cases shown in **Figure 7**. While these measures are highly insightful for model evaluation and development in the context of the void of such verification quantities in the past, there is still room for refining such constraints in terms of for example, sampling the model output similarly, the use of alternative conditional sampling methodologies, considering the implied/assumed particle size distributions in the model and the retrievals, and/or the use of instrument simulators – all of these will be discussed in Section 1.3.

1.2 Research Objectives

The background discussions above emphasize the following issues:

1) The representation of cloud ice and liquid water mass represents a *significant* shortcoming in contemporary GCMs (e.g., **Figure 1** and **Figure 2**).
2) A number of new satellite resources are available that characterize in considerably more, and/or complimentary, detail the ice and liquid cloud properties and structure.
3) Due to the differences in model representations of clouds and other hydrometeors, in conjunction with the satellite sensor sensitivities and algorithm assumptions, significant caution has to be exercised in applying satellite observations of cloud ice and liquid for model evaluation and development purposes.

With the above motivation in mind, we will combine the following elements:

1) Satellite retrievals of cloud and related properties (e.g., mass, particle size, type, vertical structure, temperature and water vapor) from CloudSat, EOS/MLS, MODIS/CERES, and SSMI/AMSR-E, etc.
2) Analyses, simulation and forecast data from a number of contemporary GCMS, including the ECMWF and NASA/MERRA analyses, NASA GEOS5, NASA GISS and NCAR CAM GCMs, and the NASA fvMMF and Harvard DARE that use complementary multi-scale modeling frameworks (MMFs).
3) The expansion of a number of preliminary lines of research from our recent work applying cloud ice and related retrievals to evaluate, diagnose and improve GCM representations of cloud ice.

to carry out the following objectives:

I) Develop a number of robust and complementary methods for making model-data cloud ice and liquid comparisons using the above contemporary satellite observations. This includes taking into account instrument sensitivities and sampling characteristics, retrieval assumptions, the implied physical representations of the model's cloud parameterizations (i.e. what components of ice/liquid are actually modeled and output), and considering comparison in both the physical retrieval space (e.g., cloud ice water content) and a more intrinsic measurement space of the sensor (e.g., reflectivity from CloudSat) by way of instrument simulators.

II) Conduct quantitative evaluations of the representations of ice and liquid clouds in a number of contemporary GCMs and provide feedback to the associated modeling teams. Each of GCMs listed is expected to undergo continued and/or significant development over the next few years either through continued operational directives (e.g., ECMWF), ongoing model development (e.g., DARE, GISS), or major upgrades/changes (e.g, NCAR CAM4, GEOS6). This includes participating in the CFMIP-2 and GCPI projects on behalf of GESO5 (see Section 1.3.6).

III) Develop, refine and test sorely needed improvements in our GCM parameterizations/ representations of the mass, particle size distribution, vertical/spatial structure, and floating/falling characteristics of the liquid and frozen hydrometeors. This will be undertaken via close collaboration with the modeling teams and facilitated by our local abilities to make code modifications and perform simulations with GEOS5, GISS and CAM GCMs.

1.3 Proposed Research

Over the lifetime of the proposed activity, we will carry out a range of model-data comparison/analysis activities, model diagnostic and sensitivity simulations, work with our collaborators to develop improvements to the parameterized cloud physics, and participate on behalf of GEOS5 in two cloud-modeling studies. In this section, we describe a few of the avenues and questions we are pursuing.

1.3.1 Total Cloud Ice and Liquid Water

Section 1.1.4 pointed out the unexploited point of validation of using CloudSat as an estimate of the *total* IWC (for IWP, MODIS/CERES, MODIS and ISCCP products can also serve as observed estimates). While this quantity is readily output in the MMF models we will be examining (i.e. Figure 6), it is *not* readily available from GCMs (usually only the "cloud" ice) despite the mass of the precipitating part being computed within the model parameterization / prognostic equation. In order to take advantage of this additional constraint, we will modify the GISS, GEOS5, and CAM parameterizations/output in order to produce the total ice field as represented by the models – and also quantify the details of any assumed particle size properties between the precipitating and non-precipitating amounts. We will work with our GMAO colleagues to also acquire such output for a short period of the MERRA analyses with these extra outputs so that the impacts of a constrained dynamical field and associated large-scale thermodynamics have on the representation of IWC and LWC. These extra atmospheric water mass fields are already internally available in the ECMWF IFS but are not routinely output – nor been subject to observations - and our ECMWF collaborator has agreed to provide the cloud water and other common fields to us as well as the precipitating components normally not output. Having both components provides an additional constraint to more accurately represent/tune the auto-conversion process as well. Such considerations and effort will also be extended to liquid water, and will include SSMI/ASMR-E LWP in the assessment of observational estimates/uncertainty.

1.3.2 Particle Size Distribution (PSD) Characterizations

Along with the utility and methodologies for characterizing and comparing total cloud ice and liquid water as well as for estimating *cloud* IWC based on the conditional sampling methodology described in Section 1.1.4, there is considerable added advantage to being able to analyze and compare particle size regimes with more specificity. This is useful not only for the model-data comparisons but also in comparing two models. For example, in carrying out the latter, it cannot be assumed that the left and right columns in **Figure 6** can be compared directly given the different PSDs assumed in each model for the three species (see Section 1.1.3). An additional consideration for such comparisons is to exploit the underlying (assumed) PSDs utilized by the models and the CloudSat retrieval.

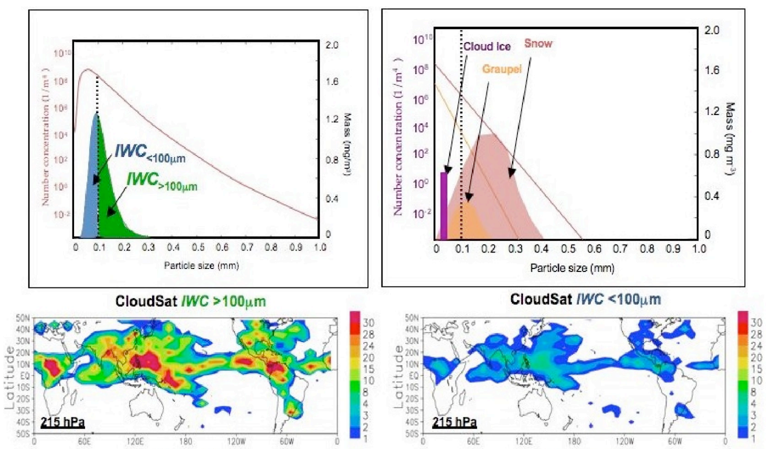
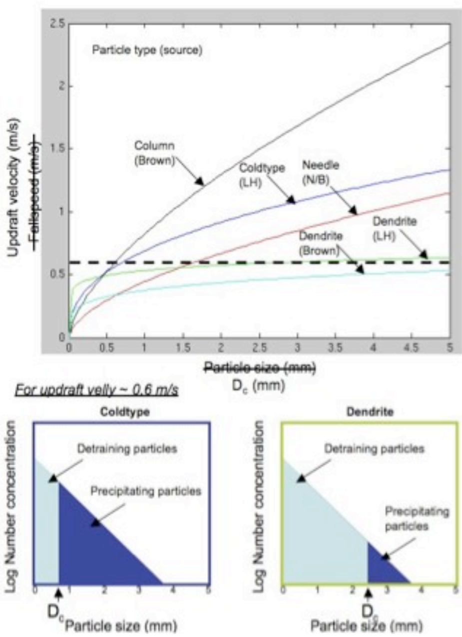


Figure 9. (upper left) Ice particle number concentration versus particle size (red curve; left axis) for a sample lognormal ice particle size distribution having parameter values: D_g= 69.0 µm, σ_{log} = 0.388, and N_T = 39800 m^{-3}. Mass distribution versus particle size (black curve; right ordinate) for the sample PSD given. A dashed line is drawn at a particle size of 100 µm that is used for IWC partitioning shown for the CloudSat data in the lower diagrams. (upper right) Similar to the left diagram but for a model with 3-species of cloud ice

The lower panels of **Figure 9** show an estimate of large (left) and small (right) particle ice using the size distribution parameters assumed within the CloudSat. In this case, each retrieval reports the shape parameters that apply to that given retrieval and that accounts – when integrated – for the given IWC estimate. Here we reconstructed the distribution (see schematic in upper left panel) and then determined the large versus small particle amount of mass with the notion – for demonstrative purposes - that cloud particles less than ~100 µm account for the *cloud* IWC and that greater is more akin to the precipitating hydrometeors. In order to compare this to MMFs for example, or intercompare MMFs, this same strategy can be used by reconstructing the total ice field from the distributions used by the model microphysical schemes (see Section 1.1.3) (see schematic in upper right panel). We will develop this methodology more rigorously and apply it to the evaluation and development/tuning refinements of the microphysical schemes of the NASA fvMMF and DARE models to provide more robust comparisons for given particle size ranges and in order to compare with CloudSat with more specificity. Such a diagnostic measure will also be useful in helping constrain (auto-) conversion and other sink/source terms in the microphysical schemes. Such methodology is also useful in constraining some GCM cloud ice (or liquid in some cases) parameterizations that use a size threshold to distinguish (floating) *cloud* IWC from that which precipitates – usually under the conditions that a given PSD is assumed for the given amount of model IWC.

1.3.3 Fall Speed Considerations

As an example of our examination of microphysical representations in GCMs, we have been considering the impacts of cloud hydrometeor fall speed assumptions. In particular, we have been exploring meaningful ways to reduce what appears to be a high IWC bias in the GISS GCM [*Li et al.*, 2005] (**Figure 1**). While part of this model-to-model "bias" is associated with the GISS GCM including in its IWC diagnostic the IWC within cumulus clouds (not normally done/accounted in most GCMs), conditional sampling of CloudSat data for convective vs non-convective clouds indicates that at most this would account for about a factor of two, and the bias is considerably larger than that. This suggests addition areas to examine. For example, the present formulation of the GISS model uses a fall speed versus particle size relation for ice that is consistent with "dendrites". This, and a number of other, relationships is represented in the upper left panel of **Figure 10** Given that temperature is an important quantity to consider when deciding how to specify/parameterize fall speed since snow particle habits tend to be defined by the local temperature and humidity during growth [e.g., *Woods et al.*, 2007], such a relation is quite restrictive – especially with deep convective processes, given that dendrites typically only form over a limited temperature range (i.e., -18 to -12C). A more representative relation would be that for unrimed radiating assemblages of plates, sideplanes, bullets, and columns (and aggregates of these types of particles) – referred to here as "cold-type" particles which form in temperatures from about -10 to as cold as -40 C [*Locatelli and Hobbs*, 1974]. The right panels show the impact of this single – more physically realistic - change in microphysical specifications on the GISS IWC. The reduction in IWC for the modified simulation is due to the fact that a much greater fraction of the cold-type particles fall at speeds that exceed a given updraft velocity than is the case for the control case/assumption (see lower left panels). Our research, we will continue to explore this, and related microphysical factors, as they apply to GISS, GEOS5 and CAM GCMs, and work with our DARE and fvMMF collaborators to examine these issues in their models as well – subsequently continuing to subject the model(s) to observational assessments and diagnostics to determine optimal representation.



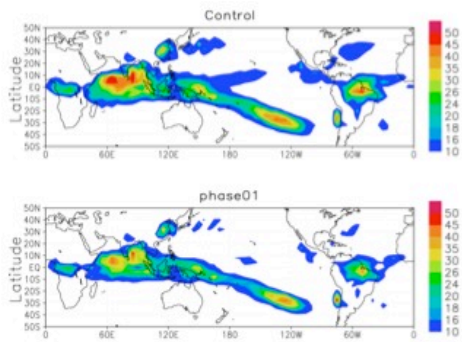


Figure 10. (upper left) Fall speed vs particle size for various ice hydrometeors. (lower left) Amount of mass that will precipitate for a given updraft velocity (0.6 m/s) based on "coldtype" or "dendrite" relationship. The light (dark) blue portion remains (precipitates). (upper right) 5-year mean IWC at 215 hPa for the for standard GISS (top) and the case when the "coldtype" fall speed relationship is used.

1.3.4 Vertical Structure of IWC

In Section 1.1.4, and from referenced figures, it is seen that the peak concentration of IWC in the tropics differs considerably between the MMFs (~550 hPa) and CloudSat (~300 hPa). Such a difference could indicate shortcomings in the models' circulation strength, microphysical processes (e.g., fall speeds as mentioned above, auto-conversion process); this in turn would likely indicate errors in the radiative and latent heating distributions, and then in turn again the dynamics. This is a case where the advent of these new data sources can be expected to provide strong constraints on the cloud-radiation-dynamical interactions if properly applied. However, such is another case where caution is warranted when considering the details of the “observatios”. In particular, the CloudSat retrieval (Section 1.1.2) combines the ice-only and liquid-only solutions via a (linear) temperature relationship. It is worth considering the impact of this somewhat-subjective manner of combining these solutions on the height of the peak IWC values. **Figure 11** shows that while the location of the

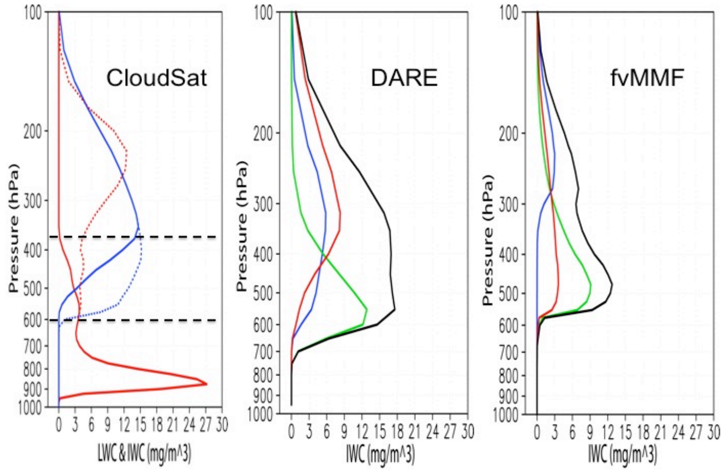


Figure 11. Annual and area (20^{o}S-20^{o}N) mean vertical profiles for CloudSat (left) IWC-only solution (blue dotted), LWC-only solution (red dotted), and the IWC (blue solid) and LWC (red solid) estimates from the combined algorithm. The upper (lower) horizontal dotted line indicates the level where the observed temperature is -15^{o} C (0^{o} C) – thresholds used in the combined algorithm. (right 2 panels) The same but is for vertical profiles of cloud ice (blue solid), graupel (green solid), snow (red solid), and their sum (dark solid) from the DARE (middle) and NASA fvMMF (right) GCMs.

CloudSat IWC peak might indeed be impacted by the method of combination (i.e. the ice-only solution peaks at about 400 rather than 350 hPa and is considerably broader), the peak values in the two models are about 100 hPa lower. This important aspect needs to be more robustly characterized, understood and simulated. We will continue to explore this issue and work with the algorithm and modeling teams to rectify this basic atmospheric property. The application of the PSD characterization described above will be important to consider in this problem in order to more robustly compare the two models and determine what part of the hydrometer budget may be leading to discrepancies. We will augment this analysis using temperature and humidity profiles from AIRS and GPS, the former (latter) of which has vertical resolutions on the order of 1km (250m), with each providing additional discriminatory information to help assess the proper/natural vertical structure. Of additional use will be to consider the same issue in the framework of radar reflectivity via the use of sensor simulators. For example, through the use of simulators described in the next subsection (i.e. top middle **Figure 12**), it is evident that apart from the artifacts associated with combining the ice-only and liquid-only solutions, the ice-only retrieval from CloudSat does not itself appear to be biased in the vertical – at least when considering conditions without mixed-phase clouds.

1.3.5 Simulator

To provide a complimentary phase space by which to compare model simulations to the observations, we will employ sensor “simulators”, namely the CloudSat simulator, to a number of the issues described above. While the use of reflectivity makes the model data comparisons more difficult in that the reflectivity is often a less intuitive quantity, it alleviates factoring in most of the assumptions and possible shortcomings associated with the retrieval algorithm. To date, we have utilized the simulator to examine the fidelity of the CloudSat algorithm [*Woods et al.*, 2008]. For example, **Figure 12** shows the reflectivity (upper left) from the application of the Quickbeam radar reflectivity simulator [*Haynes et al.*, 2008] on high-resolution (4km) MM5 regional/cloud-resolving model output over a western Pacific domain for a given synoptic condition (lower left panels). The upper middle panel indicates that the subsequent application of the CloudSat retrieval algorithm on the model cloud ice fields is relatively good – slightly over estimated. The upper right panel shows an example of just one of the sensitivity tests examined in that study in terms of the assumed particle density, size distribution and particle shape/type (in this case, assuming dendrites). Of particular relevance in validating and diagnosing model simulations is the use of simulators to ensure that the sensor sensitivity is taken into account and thus appropriate conditional filtering is being applied (e.g. a different way of approaching the issues discussed in 1.1.4). For example, CloudSat does not see IWC less than about 5 gm/m^3, and by using the simulator on the model cloud output can make sure that comparable populations are being examined – which can in fact can then be done in terms of IWC/LWC. The lower right panels of **Figure 12** show the joint PDF of reflectivity versus IWC for a set of ice-only cloud profiles from the MM5 (4km) model simulation compared to the joint PDF from CloudSat from the same western Pacific region for non-convective profiles that exhibit no surface precipitation (i.e. see Section 1.1.4).

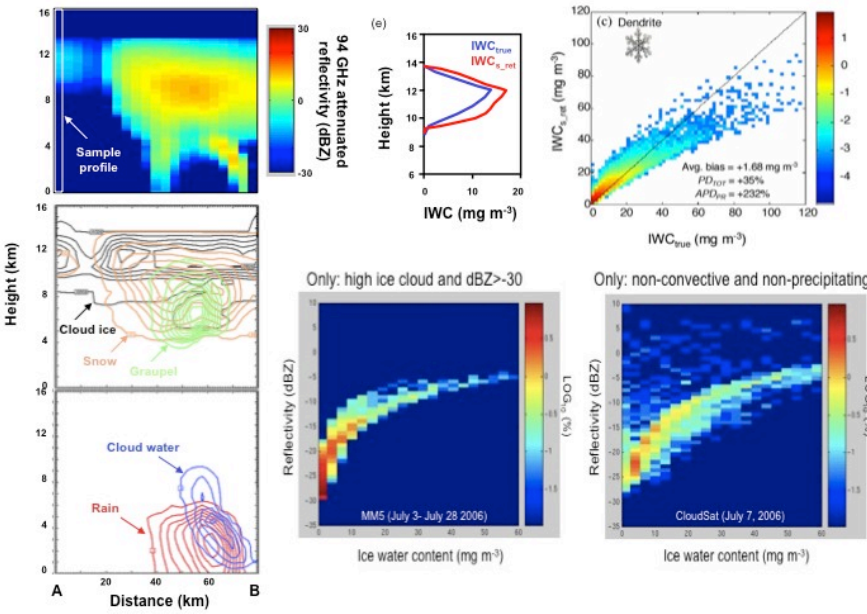


Figure 12 Unless noted, all based on MM5 model output over a W. Pacific domain.. (upper left) Vertical cross-section 94 GHz attenuated reflectivity (dBZ) from *QuickBeam, (middle left)* frozen hydrometeor mixing ratios (g kg^{-1}), (lower left) same, except for liquid hydrometeors. (upper middle and right) Comparison of modeled IWC_{true} and retrieved IWC_{s_ret} for the sample profile indicated in upper left panel. (lower middle) Joint pdf of ice water content versus 94 GHz reflectivity only for model profiles with ice-only clouds with cloud base >7km. Colorscale represents the occurrence frequency as log %. (lower right) IWC-dBZ joint pdf from CloudSat measurements, sampled to include only non-precipitating and non-convective profiles over the same domain as for the model data.

1.3.6 CFMIP and GPCI Participation

By virtue of our collaboration with GMAO, we have developed the (local) capability to perform GEOS5 simulations, including making experimental code/output modifications. This provides us the ability to undertake specific model-data evaluations and model parameterization development/sensitivity studies that simply cannot be accommodated by the limited time/resources of the GMAO model development staff. It also provides a similar extension of staff/model resources to entrain GEOS5 into community modeling efforts and experimentation that would otherwise not be possible due to personnel limitations. By agreement with GMAO, and through this proposed activity, we will perform the simulations and output the necessary fields/diagnostics to include GEOS5 as a participant in the GEWEX Cloud Feedback Model Intercomparison Study (CFMIP) Phase 2 study (cfmip.metoffice.com) as well as the GEWEX Cloud System Study (GCSS) Pacific Cross-section Intercomparison (GPCI) Phase 2 study (www.igidl.ul.pt/cgul/projects/gpci.htm). One of the project's co-I's is chair of the GPCI working group and can help ensure the GEOS5 model is adequately exercised in regards to the GPCI study. In each case, we, in conjunction with our GMAO modeling partners, will actively participate in the assessments of these models by these projects. Both these projects will greatly extend the model-data comparisons and diagnostic considerations that can/will be applied to the model.

1.4 Perceived Impact to State of Knowledge and Expected Significance

Overall the challenge is quite clear regarding the need to improve our model simulations of cloud liquid and ice mass (e.g., **Figure 1** and **Figure 2**). This level of model disagreement raises considerable questions of the reliability of our climate change predictions but also contributes to the uncertainties and errors in weather and short-term climate forecasts. Given the new A-Train resources for cloud water content, in conjunction with research activities such as that proposed here, we should expect to see a significant reduction in the shortcomings associated with the cloud liquid and ice representations in our weather and climate models. Reductions of these shortcomings will translate into a more robust model representations of cloud feedbacks in association with climate change – and thus less uncertain projections - by the time of the next IPCC assessment report – slated now for 2013.

1.5 Relevance to NASA Programs and NRA Objectives

The proposed research activities contribute to NASA's Strategic Goal 3, "Develop a balanced overall program of science, … focus on exploration", and specifically to Subgoal 3A, "Study Earth from space to advance scientific understanding and meet societal needs." Moreover, our research will exploit the tremendous investments NASA has made in EOS towards the goal of improving NASA modeling infrastructures that have been invested in and developed at GISS and GMAO/GSFC. Improvements in the latter contribute to understanding the natural system as well as provide an important feedback into EOS and subsequent observing systems as these modeling systems (namely GEOS) play a key role in the satellite retrieval process (e.g., a priori information). In regards to the Key Questions of MAP, this activity directly addresses: What further changes can be anticipated, and what can be done to improve our ability to predict such changes through improved remote sensing, data assimilation, and modeling? By improving our modeling capabilities, the work will also contribute to answering: How does the Earth system respond to natural and human-induced changes? Moreover, this research contributes to the development and improvement of 2 of the 3 "large projects and/or functional organizations that comprise the core activities of the program" – namely GISS and GEOS (including fvMMF). Finally, in ROSES 2008, MAP specifically seeks studies that address the continuum of processes and understanding behind weather and climate, and in particular "The program seeks investigations that emphasize the role of weather in the climate system, with an emphasis on the use multi-parameter observations from satellites to evaluate and characterize (i.e. validate) model simulations." Our proposed activity directly addresses this objective, and includes NASA models (GISS, GEOS5 – including the ocean-atmosphere version, fvMMF), state of the art multi-model framework simulations (fvMMF and DARE) and weather and climate reanalysis (ECMWF and MERRA) products.

1.6 Management Plan

1.6.1 Scientific Team and Responsibilities

1) D. Waliser of JPL is the PI of the proposed investigation and is responsible for the overall technical, scientific, administrative and budgetary issues for this project. The PI will provide expertise in regards to the interpretation of remote sensing observations of the atmosphere (e.g., clouds, water vapor, radiation), the design and analysis of model experimentation, and the application of satellite data to model diagnosis. The PI will also supervise the project's postdoc.
2) J.-L. Li of JPL is a co-Investigator. Dr. Li provides expertise in model physics, particularly as it relates convection, PBL and associated processes, and clouds, and in carrying out simulations with the NASA GEOS5, NASA GISS and NCAR CAM. He is also responsible for carrying out the simulations of these models and for a considerable portion of the model-data analysis, and will also help supervise the project postdoc to help in this process.
3) J. Teixeira of JPL is a co-Investigator. Dr. Teixiera provides expertise in model parameterization, particularly in terms of clouds and the PBL. He is a member of the GEWEX Cloud System Study (GCSS) scientific steering committee and chair of GCSS Pacific Cross-section Intercomparison (GPCI) working group. He will play a critical role in interpreting model-data comparisons, designing and interpreting parameterization sensitivity studies, and translating these into improved model parameterizations.
4) W. Tao and J. Chern of GSFC are collaborators, and provide the key linkage to the use, diagnosis and improvements to the NASA fvMMF model. Tao and Chern will provide fvMMF model output for the project, including enhanced versions as they are developed. Tao and Waliser have worked successfully together before on Tao et al (2008) and Waliser et al. (2008) along with an ongoing collaboration using latent heating estimates from TRMM to study the MJO.
5) J. Bacmeister of GSFC is a collaborator, and provides the key linkage to the GEOS5/GEOS6 development process. He and Dr. Li have been working effectively together for many months (and when both at GSFC) in running GEOS5 experiments collaboratively to examine issues regarding PBL, cloud structure, convection variability, cloud ice and water, etc.
6) G. Stephens of CSU is a collaborator, and Principal Investigator of the CloudSat Mission. He will lend expertise regarding CloudSat and other A-train cloud-related retrievals. Stephens regularly

visits JPL and he and Waliser have worked successfully together before [*Stephens et al.*, 2008; *Waliser et al.*, 2008; *Woods et al.*, 2008].

7) Z. Kuang of Harvard is a collaborator and the chief developer of the DARE global "cloud-resolving" GCM. He will provide model output from the DARE system and work with the research team to assess and improve the model cloud ice and liquid representations.
8) A. Del Genio of GISS is a collaborator and one of the main developers of the cloud scheme(s) in the GISS GCM. Through our previous MAP award, he has facilitated our ability to run the GISS model locally to peform the types of sensitivity studies discussed in the proposal. Dr. Del Genio will help us interpret the model-data comparisons and also requested that we undertake our cloud ice and liquid analyses on development versions of GISS.
9) R. Forbes of ECMWF is the primary cloud physics developer of the IFS system. In the interest of having the model-data evaluation be applied to the operational versions of the ECMWF analyses, he will provide the dynamic, thermodynamic and cloud-related fields from recent operational analyses as well as special diagnostic fields associated with both the floating cloud ice and falling hydrometer mass. He will aid in any interpretation related to the ECMWF modeled cloud physics.

1.6.2 Time Table

Year 1 –

- Run GEOS5 control to provide needed output to GPCI & CFMIP projects via collaboration Bacmeister.
- Code modifications to compute/output the total amounts of ice and liquid water contents in the modeled/implied hydrometers (cloud & precipitation) for GEOS5, GISS, CAM, and make control runs.
- Begin comprehensive analysis and model-data comparisons of model hydrometer/mass fields, with some emphasis on NCAR CAM and its developmental versions in consideration of the establishment of CAM4 and its contribution to AR5.
- Continue collaboration with ECMWF regarding their continuous model development process, with emphasis on our side in applying the data and interpreting the comparisons.
- Continue collaborative work started with fvMMF/GSFC and DARE/Harvard colleagues, focusing on implied/modeled particle sizes and use of the various satellite products to provide constraints.

Year 2 –

- Continue participation in the CFMIP and GPCI cloud modeling activities; performing like analyses on model sensitivity simulations of GEOS5 related to microphysical parameterization testing related to particle size, fall speed, auto-conversion specifications.
- Apply the PSD methodology (Section 1.3.2) to DARE and fvMMF models and CloudSat to examine the consistency between "small" and "large" hydrometers, and consider its impact on the cloud/hydrologic and radiative processes.
- Continue work with ECMWF IFS system and begin the evaluation of MERRA that will be done by this time and consider the differences in cloud mass when the system is constrained by observations.
- Continue to investigate fall speed and other microphysical assumptions in the GISS GCM and work with Del Genio to apply our IWC and LWC diagnostics to ongoing development work at GISS.
- Expand the studies and methods developed to date on LWC and LWP, with particular attention given to the GPCI region and framework.
- Continue model sensitivity studies of ice and liquid parameterization refinements and the diagnostic evaluation of CAM's liquid and ice representations to optimize transition to CAM4.

Year 3 –

- Complete parameterization refinements to obtain consistency in PSD representations in fvMMF, DARE and satellite observations.
- Focus on combined analyses using IWC and LWC along with reflectivity from the simulator(s) and ancillary data from AIRS and GPS to investigate and rectify the bulk shortcomings in the vertical structure of IWC in the fvMMF and DARE models.
- Continue development, sensitivity simulations and evaluation with GISS and GMAO.
- Complete the characterization of the cloud mass properties in MERRA and its evaluation relative to GEOS5. Consider, in collaboration with Bacmeister, sensitivity re-analyses for short periods.

- Continue work with ECMWF and cross-fertilize developments at ECMWF, GEOS and GISS.
- Cross-fertilize developments and findings between fvMMF and DARE microphysical representations.

Year 4

- Based on physical retrievals and radar simulator analyses/comparisons, complete refinements to fall speed and auto-conversion processes to obtain consistent vertical structure of cloud ice between models and observations.
- Integrate findings and parameterization successes across model frameworks to the extent possible, particularly between the GCMs (e.g., ECMWF, GISS, GMAO) and then fvMMF and DARE.
- Present findings and seek additional partnerships to widen the impact of the studies findings onto the next generation of GCMs (e.g., GEOS6).

1.6.3 Synergy with Other Proposals

We identify three additional proposed efforts that have strong synergy with the work proposed here. In each case, we have strong working relationships with the PIs and their collaborators. These include:

- Use high-resolution satellite observation to evaluate and advance NASA modeling ability for weather and short-term climate. Tao, Chern, Bacmeister, Waliser (unfunded) and colleagues. This effort focuses on GCE/fvMMF model/microphysics development related to clouds. The synergy between these two efforts is the added emphasis/expertise on the model and development (mode-data comparisons and observations) for their (our) effort.
- Improving the representation of shallow cumulus convection in coupled systems: Integrating satellite observations, high-resolution models and new parameterizations. Teixeira, Waliser, Fetzer, Bacmeister, Rossow and colleagues. The synergy between these two efforts is the added emphasis/expertise on the boundary layer, particularly shallow cumulus parameterization (observations, methods for model-data comparison, deep convection/ice) for their (our) effort.
- On the maintenance and use of A-train simulators to evaluate the cloudiness and precipitation parameterizations of global models. Stephens, Mace, Bacmeister, Waliser (unfunded) and colleagues. The synergy between these two efforts is the added emphasis/expertise on the observations & retrievals of A-train sensors and simulators – namely radar/CloudSat + lidar/CALIPSO, the NICAM model and precipitation (ice + liquid clouds, complementary GCMs, methods for model-data comparison, parameterization development/assessment) for their (our) effort.

1.6.4 Data Sharing Policy

We will make any and all of the GEOS5, GISS or NCAR/CAM GCM simulations that we conduct available to the MAP community so that additional diagnosis and interaction with the GMAO/GEOS development team can be carried out. In addition, any diagnostics and validation metrics developed and applied will also be made available. Evidence for past sharing activities along these lines is the PI's role as the US CLIVAR MJO Working Group co-chair and this working group's policy to publish their diagnostics and calculation codes on the web (i.e. http://www.usclivar.org/Organization/MJO_WG.html).

1.6.5 Supercomputing Resources

We request computational resources at NCCS and NAS to support the modeling activities in this proposal. We presently run GEOS5 on the NCCS Explore system. Simulations using the NCAR/CAM3 are carried out on NAS Columbia. Our NASA/GISS simulations have typically been run on the JPL supercomputer, COSMOS. To carry out the model integrations needed to diagnose the model, conduct sensitivity analyses and parameterization development/refinement, multiple realizations of single-year to multi-year (< 10 years) simulations will be needed over the four-year life cycle of this proposal. The experiments with NASA/GEOS5 AGCM will be carried out on NCCS Explore. GEOS5 requires about 60 CPU hours on 32 processors to simulate one year giving about 2,000 CPU hours per year. We estimate about 200 years worth of experimentation to be conducted, hence, a total 400,000 CPU hours. The experiments using the NCAR/CAM will be carried out on NAS Columbia with about half the number of years. The CAM requires about 40 CPU hours on 104 processors to simulate one year giving ~4,000 CPU hours per year, and thus a total of about 800,000 CPU hours for the proposed study. **Total Request: 400k CPU Hours on NCCS Explore, 400k CPU Hours on NAS Columbia.**

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Woods, C. P., M. T. Stoelinga, and J. D. Locatelli (2007), The Improve-1 Storm of 1–2 February 2001. Part Iii: Sensitivity of a Mesoscale Model Simulation to the Representation of Snow Particle Types and Testing of a Bulk Microphysical Scheme with Snow Habit Prediction, *Journal of the Atmospheric Sciences*, *In Press*.

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Wu, D. L., J. H. Jiang, R. T. Austin, M. Deng, S. L. Durden, A. J. Heymsfield, B. H. Kahn, J.-L. Li, G. G. Mace, G. M. McFarquhar, C. J. Nankervis, H. C. Pumphrey, W. G. Read, G. L. Stephens, S. Tanelli, D. G. Vane, D. E. Waliser, and J. W. Waters (2007), Aura Mls Cloud Ice Measurements and Comparisons with Cloudsat and Other Correlative Data, *J. Geoph. Res.*, Submitted.

Xie, P. P., and P. A. Arkin (1997), Global Precipitation: A 17-Year Monthly Analysis Based on Gauge Observations, Satellite Estimates, and Numerical Model Outputs, *Bull. Amer. Meteor. Soc.*, *78*(11), 2539-2558.

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Zhao, L., and F. Weng (2002), Retrieval of Ice Cloud Parameters Using the Advanced Microwave Sounding Unit, *Journal of Applied Meteorology*, *41*, 384-395.

3 Biographical Sketches

3.1 Principal Investigator: Duane Waliser

Duane Waliser
Jet Propulsion Laboratory, MS 183-501
4800 Oak Grove Drive, Pasadena, CA 91109
818-393-4094; duane.waliser@jpl.nasa.gov

Relevant Experience

Dr. Waliser is a member of the CloudSat/CALIPSO Science team, the Scientific Steering Group (SSG) of CLIVAR, a co-chair of the US CLIVAR Madden-Julian Oscillation Working Group and co-chair of the Scientific Steering Group of the WWRP-WCRP proposed Year of Tropical Convection activity. His research interests lie in climate dynamics and in global atmosphere-ocean modeling, prediction and predictability, with emphasis on the tropical atmosphere, convection, and ocean-atmosphere interaction. He joined JPL in 2004 with interests in utilizing new and emerging satellite data sets to study weather and climate as well as advance our model simulation and forecast capabilities, particularly for long-range weather and short-term climate applications..

Education

B.S. Physics	Oregon State University 1985.
B.S. Computer Science	Oregon State University 1985.
M.S. Physics	University of California, San Diego 1987.
Ph.D. Physical Oceanography	Scripps Institution of Oceanography, UCSD 1992.

Honors & Awards

NOAA Postdoctoral Fellowship for Climate and Global Change, 1992-93.
NASA Graduate Student Fellowship Recipient, 1988-1991.

Professional Experience

June 2004 - Present: Senior Research Scientist, Water and Carbon Cycle Group, Science Division, Jet Propulsion Laboratory, Pasadena, CA.

2007 - Present: Adjunct Professor and Fellow of the Joint Institute for Regional Earth System Science and Engineering (JIFRESSE), University of California, Los Angles, CA.

August 2004 - Present: Visiting Associate Faculty, Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA.

June 2004 - Present: Adjunct Associate Professor, Institute for Terrestrial and Planetary Atmospheres, State University of New York, Stony Brook, NY.

September 1999 – May 2004 Associate Professor, Institute for Terrestrial and Planetary Atmospheres, Marine Science Research Center, State University of New York, Stony Brook.

September 1993 - August 1999 Assistant Professor, Institute for Terrestrial and Planetary Atmospheres, Marine Science Research Center, State University of New York, Stony Brook.

June 1992 - August 1993 Postdoctoral Associate at UCLA Department of Atmospheric Sciences with Professors David Neelin and Roberto Mechoso.

September 1987 - May 1992 Research Assistant / Graduate Student in the Physical Oceanography curriculum at Scripps Institution of Oceanography/UCSD.

Professional Service and Synergistic Activities (selected)

Member, CALIPSO/CloudSat Science Team, Since 2008

Co-Chair, Science Steering Committee for WWRP/THORPEX-WCRP Year of Tropical Convection Activity.

Co-Chair, USCLIVAR Subseasonal Working Group, Since April 2006; http://www.usclivar.org/Organization/MJO_WG.html

Member, Scientific Steering Group (SSG) – WCRP International CLIVAR, Since June 2005.

Co-Initiator to develop a multi-institute/multi-national Experimental MJO Prediction Program administered via CDC/NOAA. See http://www.cdc.noaa.gov/MJO/.

Co-Chair, NASA-sponsored workshop: Schubert, S., R. Dole, H.v.d. Dool, M. Suarez, and D. Waliser, Proceedings from a workshop on "Prospects for improved forecasts of weather and short-term climate variability on subseasonal time scales", 16-18 April 2002, Mitchellville, MD, NASA/TM 2002-104606, 23, pp. 171, 2002.

Co-Chair US-CLIVAR/NASA sponsored workshop: Waliser, D., S. Schubert, A. Kumar, K. Weickmann, and R. Dole, Proceedings from a workshop on "Modeling, Simulation and Forecasting of Subseasonal Variability", 4-5 June 2003, U. Maryland, College Park, MD, NASA/CP 2003-104606, 25, pp. 62, NASA, GSFC Greenbelt, MD, 2003.

Professional Affiliations

Member, American Geophysical Union

Member. American Meteorological Society

Selected Publications

Waliser, D. E., W. K. Lau, J. H. Kim, 1999: The Influence of Coupled Sea Surface Temperatures on the Madden Julian Oscillation: A Model Perturbation Experiment. J. Atmos. Sci., 56, 333.

Waliser, D. E., R. A. Weller, R. D. Cess, 1999: Comparisons Between Buoy-Observed, Satellite-Derived and Modeled Surface Shortwave Flux over the Subtropical North Atlantic During the Subduction Experiment. J. Geophys. Res., 104, 31,301-31,320.

Waliser, D. E., J. Ridout, S. Xie, and M. Zhang, 2002: Variational Objective Analysis for Atmospheric Field Programs: A Model Assessment, J. Atmos. Sci., 59, 3436-3456.

Waliser, D. E., K. Jin, I.-S. Kang, W. F. Stern, S. D. Schubert, M.L.C. Wu, K.-M. Lau, M.-I. Lee, V. Krishnamurthy, A. Kitoh, G. A. Meehl, V. Y. Galin, V. Satyan, S. K. Mandke, G. Wu, Y. Liu, and C.-K. Park, 2003: AGCM Simulations of Intraseasonal Variability Associated with the Asian Summer Monsoon, Clim. Dyn., 21, 423-446.

Waliser, D. E., R. Murtugudde, and L. Lucas, 2004: Indo-Pacific Ocean Response to Atmospheric Intraseasonal Variability. Part II: Boreal Summer and the Intraseasonal Oscillation, J. Geoph. Res. - Oceans, 109, C03030, 10.1029/2003JC002002.

Waliser, D. E., 2005: Predictability and Forecasting. Intraseasonal Variability of the Atmosphere-Ocean Climate System, W. K. M. Lau and D. E. Waliser, Eds., Springer, Germ., 474.

Waliser, D. E., R. Murtugudde, P. Strutton, J.-L. Li, Subseasonal Organization of Ocean Chlorophyll: Prospects for Prediction Based on the Madden-Julian Oscillation, Geoph. Res. Lett., Vol. 32, No. 23, L23602, 10.1029/2005GL024300.

Waliser, D. E., K. M. Lau, W. Stern, C. Jones, 2003: Potential Predictability of the Madden-Julian Oscillation, Bull. Amer. Meteor. Soc, 84, 33-50.

Zheng, Y., D.Waliser, W. Stern, and C. Jones, 2004: The role of coupled sea surface temperatures in the simulation of the tropical intraseasonal oscillation, J. Climate, 17, 4109-4134.

Waliser, D. E., 2006: Intraseasonal Variability. Asian Monsoon, Ed. Bin Wang., Springer, Heidelberg, Germany, 787.

Waliser, D. E., K. Weickmann, R. Dole, S. Schubert, O. Alves, C. Jones, M. Newman, H-L Pan, A. Roubicek, S. Saha, C. Smith, H. van den Dool, F. Vitart, M. Wheeler, J. Whitaker, 2006: The Experimental MJO Prediction Project. Bull. Amer. Meteorol. Soc., 87, 425-431.

Waliser, D. E., 2006: Predictability of Tropical Intraseasaonal Variability. Predictability of Weather and Climate, T. Palmer and R. Hagedorn, Eds., Cambridge University Press, 718.

Schwartz, M. J., D. E. Waliser, B. Tian, J. F. Li, D. L. Wu, J. H. Jiang, and W. G. Read, 2007: MJO in EOS MLS cloud ice and water vapor. Geophys. Res. Lett., In Press

Jiang, X., and D. E. Waliser, 2008, Northward Propagation of the Subseasonal Variability over the Eastern Pacific Warm Pool, GRL, In Press.

Vavrus, S., and D. E. Waliser, 2008: An improved parameteri-zation for simulating Arctic cloud amount in the CCSM3 climate model. J. Climate. In Press.

Wu, D. L., R. T. Austin, M. Deng, S. L. Durden, A. J. Heymsfield, J.-L. Li, G. M. McFarquhar, I. V. Pittman, G. L. Stephens, S. Tanelli, D. G. Vane, D. E. Waliser, 2008, Comparisons of Global Cloud Ice from MLS, CloudSat, and Correlative Data Sets, JGR Special CloudSat Section, Submitted.

3.2 Co-Investigator: Jui-Lin (Frank) Li

Jet Propulsion Laboratory/CalTech, MS 183-601, 4800 Oak Grove Drive
Pasadena, CA 91109; email: jli@jpl.nasa.gov

EDUCATION

1994, Ph.D. , Atmospheric and Oceanic Sciences, University of Wisconsin-Madison
1985, M.S. , Atmospheric Sciences, National Taiwan University, Taiwan
1982, B.S. , Atmospheric Sciences, National Taiwan University, Taiwan

SCIENTIFIC EXPERTISE

- **Global climate modeling and model physical parameterizations**
  Modeling climate and hydrological processes; Modeling dry/moist planetary boundary layer (PBL) including development and revision of PBL cumulus and stratocumulus schemes; Modeling and modifying stable cloud and deep convection schemes used in GCMs.
- **Model and data comparison**
  Comparing satellite observed and modeled parameters for cross validation and evaluation for the improvement of physical parameterizations and understanding the hydrological processes
- **Data assimilation**
  In developing assimilation system using satellite data. Perform analysis of the impact of the assimilated information on a system and evaluation of the interaction between the schemes.

SELECTED PUBLICATIONS

Li, J-L F, D. Waliser, et al., 2008, Cloud Diabatic Heating Comparisons between Measurements, ECMWF and GEOS5 Analyses, and GCM Simulations, in preparation.

Li, J-L F, D. Waliser, et al., 2008, Troposphere Cloud Liquid Water: Satellite Measurements, ECMWF and GEOS5 Analyses, and GCM Simulations, in preparation.

Dong L. Wu, et al, **Jui-Lin Li**, 2008: Aura MLS Cloud Ice Measurements and Comparisons with CloudSat and Other Correlative Data, submitted to JGR, in review.

Waliser, D.E., **J. F. Li**, et al, 2008: Cloud Ice: A Climate Model Challenge With Signs and Expectations of Progress, *J. G.R., submitted*.

Tao, Wei-Kuo, et al and **Jui-Lin Li**, et al.,**2008**: A Multi-scale Modeling System: Developments, Applications and Critical Issues, BAMS, accepted.

Schwartz, M.J., and, **J-L.F. Li**, et al., "Validation of the Aura Microwave Limb Sounder Temperature and Geopotential Height Measurements," *J. Geophys. Res. 113*, D15S11, doi:10.1029/2007JD008783, **2008**.

Schwartz, M. J., D. E. Waliser, B. Tian, **J. F. Li**, D. L. Wu, J. H. Jiang, and W. G. Read, 2008: MJO in EOS MLS cloud ice and water vapor. *Geophys. Res. Lett.*, in press.

Woods, C.P., D Waliser, **J-L F. Li**, R Austin, G Stephens, D Vane, W Tao, A Tompkins Evaluating CloudSat Ice Water Retrievals Using a Cloud Resolving Model: Sensitivities to Frozen Particle Properties and Implications for Model-Data Comparisons, **2008**, JGR, conditional accepted, under revision.

Li, Jui-Lin, D. Waliser, J. Jiang and A. Thompkins, 2006; Assessing Consistency between EOS MLS and ECMWF Analyzed and Forecast Estimates of Cloud Ice, submitted to *Geophys. Res. Lett*.

Su, Hui, D. E. Waliser, J. H. Jiang, **J.-L. F. Li**, W. G. Read, J. W. Waters and A. M. Tompkins, 2006: Relationships among upper tropospheric water vapor, clouds and SST: ECMWF analyses and GCM simulations, submitted to *Geophys. Res. Lett*.

Xin Lin, **J.L. Li,** et al., 2006, A View of Hurricane Katrina with Early 21st Century Technology, EOS.

Shen, B.-W., et. al., **and J.-L. F Li** , 2006, Hurricane forecasts with a global mesoscale-resolving model: Preliminary results with Hurricane Katrina (2005), *Geophys. Res. Lett*., 33, L13813, doi:10.1029/2006GL026143.

Li Jui-Lin and D. Waliser et al., 2005: Comparisons of EOS MLS Cloud Ice Measurements with ECMWF analyses and GCM Simulations: Initial Results, *Geophys. Res. Lett.*., 32, L18710,doi: 10.1029/2005GL023788, 2005.

Li, Jui-Lin F., Martin K., J. D. Farrara and R. Mechoso, 2002: The Impact of the Improvement of optical properties of stratocumulus clouds in the UCLA AGCM, *Mon. Wea. Rev.*, 130, 1433-1441.

Wang, F.-J. **and J-L. F. Li**, 2002: Improved Shallow Cumulus Process In The Central Weather Bureau Global Forecast System, Meteorological Bulletin, Vol. 44 No.4, 1-23.

Li, Jui-Lin F., 1994: On Shallow Cumulus Parameterization Schemes for General Circulation Model Planetary Boundary Layers**, PhD thesis**, Department of Atmospheric and Oceanic Sciences, University of Wisconsin, Madison, Wisconsin.

3.3 Co-Investigator: Joao Teixeira

Jet Propulsion Laboratory, 4800 Oak Grove Drive • Ms 169-237, Pasadena, CA 91109

Education

Licentiate (Geophysical Sci.–Oct/92) and PhD (Meteorology-Jan/2000), Univ. Lisbon, Portugal.

Professional Experience

2008 – present	Research Scientist, Jet Propulsion Laboratory, Pasadena, CA, USA
2005–2007	Senior Scientist, NATO Undersea Research Centre, La Spezia, Italy.
2000–2005	UCAR Scientist, Naval Research Laboratory, Monterey, CA, USA.
1993–1999	Scientist, European Centre for Medium-range Weather Forecasts, Reading, UK.

Professional Activities

- Associate Editor: *Monthly Weather Review* – since 2005
- Chair: GCSS Pacific Cross-section Intercomparison (GPCI) working group – since 2005
- Member: GEWEX Cloud System Study (GCSS) scientific steering committee - since 2004
- Member: American Meteorological Society STAC Committee on 'Boundary Layers and Turbulence' - 2004-2006.
- Member: Advisory Group, NSF/NOAA Climate Process Team (CPT) on "Low-latitude cloud feedbacks on climate sensitivity" – 2003-2006.
- Program Leader: NATO Air-Sea Interaction Program – 2005-2007.
- Invited to brief: Department of Energy BERAC sub-committee meeting on 'Cloud Parameterizations and Abrupt Climate Change', 2004.

Refereed Publications (selected)

Teixeira, J., and C. A. Reynolds, 2008: Stochastic nature of physical parameterizations in ensemble prediction: a stochastic convection approach. *Mon. Wea. Rev*., **136**, 483-496.

Teixeira, J., P. May, M. Flatau, and T.F. Hogan, 2008: On the sensitivity of the SST from a global ocean-atmosphere coupled system to the parameterization of boundary layer clouds. *J. Marine Sys.*, **69**, 29-36.

Teixeira, J., C. Reynolds, and K. Judd, 2007: Time-step sensitivity of non-linear atmospheric models: numerical convergence, truncation error growth and ensemble design. *J. Atmos. Sci.*, **64**, 175-189.

Teixeira, J., J. P. Ferreira, P.M.A. Miranda, T. Haack, J. Doyle, A. P. Siebesma and R. Salgado, 2004: A new mixing length formulation for the parameterization of dry convection: implementation and evaluation in a mesoscale model. *Mon. Wea. Rev*., **132**, 2698-2707.

Teixeira, J., and S. Cheinet, 2004: A simple mixing length formulation for the eddy-diffusivity parameterization of dry convection. *Bound. Layer Meteor.*, **110**, 435-453.

Cheinet, S. and J. Teixeira, 2003: A simple formulation for the eddy-diffusivity parameterization of cloud-topped boundary layers. *Geophys. Res. Letters*, **30 (18)**, 1930.

Teixeira, J. and T.F. Hogan, 2002: Boundary layer clouds in a global atmospheric model: simple cloud cover parameterizations. *J. Climate*, **15**, 1261-1276.

Teixeira, J., 2001: Cloud fraction and relative humidity in a prognostic cloud fraction scheme. *Mon. Wea. Rev*., **129**, 1750-1753.

Duynkerke, P.G. and J. Teixeira, 2001: Comparison of the ECMWF Reanalysis with FIRE I observations: diurnal variation of marine stratocumulus. *J. Climate*, **14**, 1466-1478.

Teixeira, J., 1999: Simulation of Fog with the ECMWF Prognostic Cloud Scheme. *Quart. J. Roy. Meteor. Soc*., **125-B**, 529-553.

4 Current and Pending Support

4.1 Principal Investigator: D. Waliser

Current Awards

PI	Award/Project Title	Program Info	Period & Total Budget	Commitment (Work Year)
D. Waliser	Exploiting Satellite Observations And Cloud-Resolving Models To Improve GCM Representations Of Cloud-Radiation-Dynamical Interactions	MAP – NASA D. Anderson Donald.Anderson-1@hq.nasa.gov 202-358-1432	10/1/2005-9/31/2008 $900k	0.10
S. Schurbert/GSFC D. Waliser : co-I	Pathways to predictability on subseasonal time scales: assessing the role of tropical forcing and land surface conditions	MAP – NASA D. Anderson Donald.Anderson-1@hq.nasa.gov 202-358-1432	10/1/2005-9/31/2010 $2,500k	0.08
E. Fetzer/JPL D. Waliser : co-I	A Merged Atmospheric Water Data Set from the A-Train	NEWS – NASA J. Entin jared.k.entin@nasa.gov	10/1/2005-9/31/2010 $1,500k	0.08
D. Waliser	Predictability and Model Verification of the Water and Energy Cycles: Linking Local, Regional and Global Scales	NEWS – NASA J. Entin jared.k.entin@nasa.gov	10/1/2006-9/31/2009 $600k	0.08
D. Waliser	Integrating CloudSat and A-Train Observations of Upper-Tropospheric Cloud and Hydrological Processes: Application to GCM Evaluation and Improvement	CloudSat Projrect Office	10/1/2007-9/31/2008 $150k	0.08
S. Hook/JPL D. Waliser: co-I	Using Large Inland Water Bodies to Characterize and Predict Regional Climate Change	EOS – NASA Dr. Lucia Tsaoussi (202) 358-4471	10/1/2006-9/31/2009 ~$450k	0.08

Pending Awards

PI	Award/Project Title	Program Info	Period & Total Budget	Commitment (Work Year)
M. Moncrieff/NCAR D. Waliser: co-I	Meso-Convective Organization And Large-Scale Convective Coherence In The Tropics: Modeling, Analysis And Prediction	MAP – NASA Climate/Weather D. Anderson Donald.Anderson-1@hq.nasa.gov 202-358-1432	10/1/2008-9/31/2012 $1.5M	0.08
J. Teixera/JPL D. Waliser: co-I	Improving the representation of shallow cumulus convection in coupled systems: Integrating satellite observations, high-resolution models and new parameterzations	MAP – NASA Climate/Weather D. Anderson Donald.Anderson-1@hq.nasa.gov 202-358-1432	10/1/2008-9/31/2012 $960k	0.08
B. Tian/UCLA D. Waliser: co-I	Intraseasonal Variations of Atmospheric Composition and	MAP – NASA Composition/GMI	10/1/2008-9/31/2012	0.08

	Their Connection to the Madden-Julian Oscillation: Satellite Data Analysis and Chemistry/Transport Modeling	D. Anderson Donald.Anderson-1@hq.nasa.gov 202-358-1432	$980k	

4.2 Co-Investigator: J.-L. Li

Current Awards

PI	Award/Project Title	Program Info	Period & Total Budget	Commitment (Work Year)
D. Waliser J.-L. Li/co-I	Exploiting Satellite Observations And Cloud-Resolving Models To Improve GCM Representations Of Cloud-Radiation-Dynamical Interactions	MAP – NASA D. Anderson Donald.Anderson-1@hq.nasa.gov 202-358-1432	10/1/2005-9/31/2008 $900k	0.20
D. Waliser	Predictability and Model Verification of the Water and Energy Cycles: Linking Local, Regional and Global Scales	NEWS – NASA J. Entin jared.k.entin@nasa.gov	10/1/2006-9/31/2009 $600k	0.05
D. Waliser J.-L. Li/co-I	Integrating CloudSat and A-Train Observations of Upper-Tropospheric Cloud and Hydrological Processes: Application to GCM Evaluation and Improvement	CloudSat Projrect Office	10/1/2007-9/31/2008 $150k	0.20

Pending Awards

Proposer Name	Award/Project Title	Program Info	Period & Total Budget	Commitment (Work Year)
J. Teixera/JPL J.-L. Li: co-I	Improving the representation of shallow cumulus convection in coupled systems: Integrating satellite observations, high-resolution models and new parameterzations	MAP – NASA Climate/Weather D. Anderson Donald.Anderson-1@hq.nasa.gov 202-358-1432	10/1/2008-9/31/2012 $960k	0.10

4.3 Co-Investigator: J. Teixeira

Current Support

Proposer Name	Award Project Title	Sponsoring Agency	Performance Period Budget	Total WY Commitment
Joao Teixeira	Unified Parameterization of the Boundary Layer	ONR	01/2008 – 12/2010 $450K	0.2
Eric Fetzer	A Multi-Sensor Water Vapor Climate Data Record Using Cloud Classification	NASA MEaSUREs	06/2008 – 06/2013 $2.6M	0.2

Pending Support

Proposer Name	Award Project Title	Sponsoring Agency	Performance Period Budget	Total WY Commitment
Joao Teixeira	Global characterization of atmosphere-surface exchanges: a space-based description of the atmospheric boundary layer	NASA NEWS	10/2008 – 09/2012 $900K	0.3

5 Statements of Commitment/Support

5.1 J.-L. Li

JPL

May 5, 2008

Dr. Duane Waliser
Jet Propulsion Laboratory, MS 183-505
4800 Oak Grove Drive, Pasadena, CA 91109
818-393-4094 (tel); 818 354 0966 (fax)
duane.waliser@jpl.nasa.gov

Dear Dr. Waliser,

I acknowledge that I am identified by name as a co-Investigator to the investigation, entitled "**Judicious Application of Satellite Observations To Evaluate And Improve Cloud Ice and Liquid Water Representations In Conventional and Multi-Scale Weather & Climate Models**", that you are submitting to the NASA ROSES 2008 MAP Climate/Weather Announcement **NNH08ZDA001N**, and that I intend to participate in this activity as outlined in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal.

Sincerely,

Jui-Lin (Frank) Li, PhD
Scientist, Earth Sciences Division
Jet Propulsion Laboratory/NASA
MS 183-601
California Institute of Technology
4800 Oak Grove Drive, Pasadena, CA 91109

5.2 J. Teixeira

8 May 2008

Dr. Duane Waliser
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

Dear Dr. Waliser:

I acknowledge that I am identified by name as Co-Investigator to the investigation, entitled "Judicious Application of Satellite Observations To Evaluate And Improve Cloud Ice and Liquid Water Representations In Conventional and Multi-Scale Weather & Climate Models", that is submitted by Principal Investigator Duane Waliser to the NASA Research Announcement NNH08ZDA001N-MAP, and that I intend to carry out all responsibilities identified for me in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal.

Sincerely,

Joao Teixeira

5.3 J. Bacmeister, J. Chern & W.K. Tao

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland
20771

May 1, 2008

Dr. Duane Waliser
Jet Propulsion Laboratory, MS 183-505
4800 Oak Grove Drive, Pasadena, CA 91109
818-393-4094 (tel); 818 354 0966 (fax)
duane.waliser@jpl.nasa.gov

Dear Dr. Waliser,

We acknowledge that we are identified by name as Collaborators to the investigation, entitled "**Judicious Application of Satellite Observations To Evaluate And Improve Cloud Ice and Liquid Water Representations In Conventional and Multi-Scale Weather & Climate Models**", that you are submitting to the NASA ROSES 2008 MAP Climate/Weather Announcement **NNH08ZDA001N**, and that we intend to participate in this activity as outlined in this proposal. We understand that the extent and justification of our participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal.

Sincerely,

Wei-Kuo Tao
Julio Bacmeister
Juindar Chern

NASA Goddard Space Flight Center
Greenbelt, MD

5.4 G. Stephens

Colorado State University
Knowledge to Go Places

Department of
Atmospheric Science
Fort Collins, Colorado 80523-1371
(970) 491-8360
FAX: (970) 491-8449
http://www.atmos.colostate.edu

May 11, 2008

Dr. Duane Waliser
Jet Propulsion Laboratory, MS 183-505
4800 Oak Grove Drive, Pasadena, CA 91109
818-393-4094 (tel); 818 354 0966 (fax)
duane.waliser@jpl.nasa.gov

Dear Dr. Waliser,

I acknowledge that I am identified by name as a Collaborator to the investigation, entitled "**Judicious Application of Satellite Observations To Evaluate And Improve Cloud Ice and Liquid Water Representations In Conventional and Multi-Scale Weather & Climate Models**", that you are submitting to the NASA ROSES 2008 MAP Climate/Weather Announcement **NNH08ZDA001N**, and that I intend to participate in this activity as outlined in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal.

Sincerely,

Graeme Stephens
Department of Atmospheric Sciences
Colorado State University
Fort Collins, CO

5.5 A. Del Genio

From: adelgenio@giss.nasa.gov
Subject: **Collaboration on MAP proposal**
Date: May 6, 2008 9:46:20 AM PDT
To: duane.waliser@jpl.nasa.gov
Return-Path: <adelgenio@giss.nasa.gov>

May 6, 2008

Dr. Duane Waliser
Jet Propulsion Laboratory, MS 183-505
4800 Oak Grove Drive, Pasadena, CA 91109
818-393-4094 (tel); 818 354 0966 (fax)
duane.waliser@jpl.nasa.gov

Dear Dr. Waliser,

I acknowledge that I am identified by name as a Collaborator to the investigation, entitled "Judicious Application of Satellite Observations To Evaluate And Improve Cloud Ice and Liquid Water Representations In Conventional and Multi-Scale Weather & Climate Models", that you are submitting to the NASA ROSES 2008 MAP Climate/Weather Announcement NNH08ZDA001N, and that I intend to participate in this activity as outlined in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal.

Sincerely,
Anthony D. Del Genio
NASA Goddard Institute for Space Studies
2880 Broadway
New York, NY 10025
212-678-5588
<mailto:adelgenio@giss.nasa.gov>adelgenio@giss.nasa.gov

5.6 Z. Kuang

Harvard University

Department of Earth and Planetary Sciences

20 Oxford Street, Cambridge, Massachusetts 02138

Telephone: (617) 495-2351 FAX: (617) 495-8839

May 1, 2008

Dr. Duane Waliser
Jet Propulsion Laboratory, MS 183-505

4800 Oak Grove Drive, Pasadena, CA 91109

818-393-4094 (tel); 818 354 0966 (fax)
duane.waliser@jpl.nasa.gov

Dear Dr. Waliser,

I acknowledge that I am identified by name as a Collaborator to the investigation, entitled "Judicious Application of Satellite Observations To Evaluate And Improve Cloud Ice and Liquid Water Representations In Conventional and Multi-Scale Weather & Climate Models", that you are submitting to the NASA ROSES 2008 MAP Climate/Weather Announcement NNH08ZDA001N, and that I intend to participate in this activity as outlined in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal.

Sincerely,

Zhiming Kuang

Assistant Professor

Dept. Earth and Planetary Science and School of Engineering and Applied Sciences

Harvard University

5.7 R. Forbes

May 13, 2008

Dr. Duane Waliser
Jet Propulsion Laboratory, MS 183-505
4800 Oak Grove Drive, Pasadena, CA 91109
818-393-4094 (tel); 818 354 0966 (fax)
duane.waliser@jpl.nasa.gov

Dear Dr. Waliser,

I acknowledge that I am identified by name as a Collaborator to the investigation, entitled **"Judicious Application of Satellite Observations To Evaluate And Improve Cloud Ice and Liquid Water Representations In Conventional and Multi-Scale Weather & Climate Models"**, that you are submitting to the NASA ROSES 2008 MAP Climate/Weather Announcement **NNH08ZDA001N**, and that I intend to participate in this activity as outlined in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal.

Sincerely,

Dr Richard Forbes
ECMWF
Shinfield Park, Reading
RG2 9AX, U.K.
Phone: (+44/0) 118 949 9044
Email: richard.forbes@ecmwf.int

6 Budget Justification

6.1 Budget Narrative

6.1.1 Rationale and Basis of Estimate

The budget estimate was prepared using JPL's Pricing System and the current internally published Cost Estimation Rates and Factors.

The derivation of the cost estimate is a grassroots methodology based on the expert judgment from a team of experienced individuals who have performed similar work. The team provided the necessary relevant experience to develop a credible and realistic cost estimate. The cognizant individuals identified and defined the products and the schedule needed to complete the tasks for each work element. Then they generated the resource estimates for labor, procurements, travel, and other direct costs for each work element. The resource estimates were aggregated and priced using JPL's Pricing System. JPL's process ensures that lower level estimates are developed and reviewed by the performing organizations and their management who will be accountable for successfully completing the proposed work scope within its estimated cost.

Support in the amount of $12.5k for approximately 16 TB of disk storage is requested to accommodate the storage and processing of the proposed satellite and model data sets. This request/cost occurs in Year 1. In Year 3, there is an additional request of $7.5k to add additional capacity to the project's storage capabilities to accommodate the additional years of satellite data and additional multi-scale and other GCM output.

Support is requested in the amount of $6k for travel per year. This will support three trips per year, by the PI or Co-Is, to interact with the project collaborators (i.e. namely the modeling groups) and/or to present research findings at national and international workshops and conferences (e.g., AGU, GEWEX, AMS).

Support is requested in the amount of $5k for publication costs per year. This is based on prior year publication activity and page charge rates in AGU and AMS journals.

Support is requested in the amount of $3k for miscellaneous computer support costs per year. This includes minor hardware (e.g., printer media, backup media, software upgrades, license support).

6.1.2 Personnel and Work Effort

Work Effort in Fraction of a Work Year						
Name	**Institution**	**Role**	**Year 1**	**Year 2**	**Year 3**	**Year 4**
Duane Waliser	JPL	PI	0.17	0.17	0.17	0.17
J.-L. Li	JPL	Co-I	0.25	0. 25	0. 25	0. 25
J. Teixeira	JPL	Co-I	0.08	0. 08	0. 08	0. 08
TBD	JPL	Postdoc	1.0	1.0	1.0	1.0

6.1.3 Facilities and Equipment

Apart from the basic facility infrastructure at JPL, the special facilities and equipment required to complete this project include: JPL Supercomputer, NAS/NCCS Supercomputers and the requested data storage (see above). Supercomputer time will be requested from both JPL and NAS/NCCS to perform GCM simulations. Presently, we utilize the NCCS facility to carry out simulations with the GEOS5 GCM and a request will be made to continue these simulations for the purpose of this work. Similarly, we use the NAS facility for NCAR CAM simulations and to support simulations of the DARE model by our present MAP co-I and proposed MAP collaborator Z. Kuang. We will be making an additional request for NAS resources to support the computing activities associated with these models. Finally, JPL supercomputer time has been, and is proposed to be, used to support our simulations with the NASA GISS GCM. We based our cost estimate of the disk space request on a quote from Robert Kelly, Partners Data Systems, Inc., 3663 Via Mercado, La Mesa, CA 91941 USA, Voice: 619-415-2000 x333

SurfRAID TRITON 16FA4 w/ 16x1TB disks = $12,135
4Gbit Fibre Channel, 2GB Cache, Dual Host Interface, 3U Rack-Mount

6.2 Budget Details

6.2.1 Budget Spreadsheet

JPL
Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, California 91109

Detailed Budget (Basis of Estimate)

09 NRA/ROSES 5YR Ver 12.0

)POSAL TITLE:

Proposal Title: Judicious Application of Satellite Observations To Evaluate And Improve Cloud Ice and Liquid Water Representations In Conventional and Multi-Scale Weather & Climate Models

)GRAM:

Program Name: ROSES 08, MAP - Weather+Climate

IRECT COMPENSATION

		FY 2009	FY 2010	FY 2011	FY 2012	FY 2013
JPL LABOR CLASS.		2,080	2,080	2,080	2,120	2,080
Y	Duane Waliser	0.17	0.17	0.17	0.17	-
Y	Frank Li	0.25	0.25	0.25	0.25	-
Y	Joao Teixera	0.08	0.08	0.08	0.08	-
Y	Name (Co-I 3)	-	-	-	-	-
Y	Name (Co-I 4)	-	-	-	-	-
Y	Name (Co-I 5)	-	-	-	-	-
N	-	-	-	-	-	-
N	-	-	-	-	-	-
N	-	-	-	-	-	-
SUBCONTRACTOR WORKHOURS		-	-	-	-	-
Estimated Group Sup/Secr'y Hours ==>		0.03	0.03	0.03	0.03	-
	TOTAL WORKYEARS A1	0.53	0.53	0.53	0.53	-

					FY 2009 $k	FY 2010 $k	FY 2011 $k	FY 2012 $k
IRECT COMPENSATION		LABOR COST SUBTOTAL		A2	58.2	60.8	63.2	67.1
		APPLIED FRINGES COSTS		A3	28.2	29.5	30.6	32.6
		JPL DIRECT COMPENSATION		TOTAL A	86.4	90.2	93.8	99.7
	Y	Name (Gov't Co-I 1)						
	Y	Name (Gov't Co-I 2)						
RAVEL		DESTINATION	Cost/Trip					
	1	Scientific Meetings			6.0	6.0	6.0	6.0
	2	0			-	-	-	-
				TOTAL TRAVEL B	6.0	6.0	6.0	6.0
ERVICE		(LIST BY TYPE)						
	1	0			-	-	-	-
	2	0			-	-	-	-
	3	0			-	-	-	-
	4	Name (Caltech IA Co-I)			-	-	-	-
				TOTAL SERVICES C	-	-	-	-
ROCUREMENTS		(LIST BY TYPE, e.g. CONTRACT LABOR, CONSULTANTS, MATERIALS & SUPPLIES, EQUIP., etc.)						
D1 CONTRACTS/	1	Postdoc			80.0	82.0	84.0	86.0
	2	0			-	-	-	-
	3	Name (University Co-I 1)			-	-	-	-
	4	Name (University Co-I 2)			-	-	-	-
CHARGEBACKS	5	*Chargebacks calculated at $5.04/Hour (FY08 dollars) - Autocalc*			4.7	4.7	4.7	4.8
				TOTAL CONTRACTS D1	84.7	86.7	88.7	90.8
D2 CONSULTANTS	4	0			-	-	-	-
	5	0			-	-	-	-
				TOTAL CONSULTANTS D2	-	-	-	-
				TOTAL CONTRACTS AND CONSULTANTS D1+D2	84.7	86.7	88.7	90.8
D3 PO's EQUIP.	1	Computer Storage	(Over $5k)		12.5	-	7.5	-
	2	0	(Over $5k)		-	-	-	-
	2	0	(Over $5k)		-	-	-	-
	3	Misc.	(Remainder)		-	-	-	-
				TOTAL PO - EQUIPMENT D3	12.5	-	7.5	-
D4 SUPPLIES	4	0			-	-	-	-
	5	Computer			4.0	4.0	4.0	4.0
	6	Publication Costs			5.0	5.0	5.0	5.0
				TOTAL PO - SUPPLIES D4	9.0	9.0	9.0	9.0
				TOTAL PO D3+D4	21.5	9.0	16.5	9.0
				TOTAL PROCUREMENTS D	106.2	95.7	105.2	99.8
ACILITIES		(LIST AS EITHER NEW CONSTRUCTION OR MODIFICATION - IF C OF F FUNDED, DO NOT INCLUDE)						
	1	0			-	-	-	-
	2	0			-	-	-	-
				TOTAL FACILITIES E	-	-	-	-
ULTIPLE PROGRAM SUPPORT (MPS)				F	13.4	13.3	13.3	13.4
OTAL DIRECT COST				(SUM A THROUGH F) G	212.1	205.3	218.4	219.0
LLOCATED DIRECT COSTS (ADC)								
		H1. APPLIED ENG & SCI (Labor) ADC		H1	24.6	24.3	24.7	25.0
		H2. APPLIED CONTRACTS ADC		H2	2.9	3.0	3.0	3.4
		H3. APPLIED PURCHASE ORDERS (PO) ADC		H3	2.0	0.9	1.3	0.7
)STS SUBTOTAL				(SUM A THROUGH H) I	241.6	233.4	247.5	248.0
		I1. APPLIED GENERAL ADC		I1	24.3	23.9	25.0	25.6
OTAL JPL COSTS				(I + I1) J	265.9	257.3	272.5	273.6
WARD FEE				K	4.2	4.1	4.3	4.4
RAND TOTAL COSTS				(J + K) L	270.1	261.4	276.8	278.0

JPL Cost Accumulation System

Introduction

All costs incurred at the Laboratory, including JPL applied burdens, are billed to the Government as direct charges at the rates in effect at the time the work is accomplished.

Allocated Direct Costs

Allocated Direct Cost (ADC) rates contain cost elements benefiting multiple work efforts, including Project Direct, MPS, and Support and Services activities. Rate applications for cost estimates are specific to the given category as stated below:
1) Engineering and Science (E&S)
2) Procurement: Purchase Order, Subcontract, Research Support Agreement (RSA)
3) General and Administrative (G&A): Basic, RSA
4) Specialized G&A applications: Remote Site
The accounting process fully distributes these costs to the respective project/task(s).

Multiple Program Support

The Multiple Program Support (MPS) rate applies costs for program management and technical infrastructure. Cost estimates and system application tools will apply the composite rate to all project direct hours charged to projects managed by JPL.

Employee Benefits

All costs of employee benefits are collected in a single intermediate cost pool, which is then redistributed to all cost objectives as a percentage of JPL labor costs, including both straight-time and overtime. Functions and activities covered by this rate include paid leave, vacations, and other benefits including retirement plans, group insurance plans, and tuition reimbursements.

Award Fee

The NASA/Caltech Prime Contract is a cost plus award fee contract. Sponsors placing funds on contract contribute a percentage of task order dollars to the award fee. The local NASA Management Office (NMO) determines the rate (percentage) annually. NASA applies the rate (percentage) to the funding available net of the CAAS charge.

For this proposal the estimated costs have been derived in the same manner as stated above. However, presentation of the estimated costs in the required NSPIRES tables has been adapted in the following ways:

1. The costs for Employee Benefits are included in the Direct Labor costs stated in this proposal.
2. Engineering and Science ADC and Procurement ADC along with MPS costs are displayed in the "Other" category in the Other Direct Costs section.
3. G&A is shown in the Facilities and Administrative Costs section.
4. The Award Fee is displayed in the Other Applicable Costs section. The Award Fee annual percentage is 1.59%.
5. JPL's forecasted labor rates equal an hourly laboratory-wide average for each job family and are further broken down by career level within the job family. Labor cost estimates apply the family average or family average career level rate to the estimated work hours. An actual individual's labor is considered discrete and confidential information and is only released on an exception basis and only if a statement of work identifies that specific individual as the only one able to perform a task. The use of family average or family average career level rates is consistent with the JPL CAS disclosure statement and the Cost Estimating Rates and Factors CDRL published in response to a requirement in NASA prime contract NAS7-03001 I-10 (d) (1).

The proposed budget of the NRA proposal also covers labor costs for serving on NASA peer-review panels and advisory committee at the request of NASA discipline scientists or program managers.

6.2.2 Budget Itemizations

Except for the request for support for data storage in Year 1 and Year 3, each budget year consists of the same items. These are discussed below.

Direct Labor

The amount of requested salary support, in terms of FTEs, is described in the Table in Section 6.1.2, with the actual expenditure request given in the budget sheet in Section 6.2.1.

Other Direct Costs

Travel

- The PI will attend a domestic conference to present results in each year of the project. ($2K).
- The PI will visit GSFC to discuss strategy and scientific progress and results with GEOS/fvMMF developers in each year of the project ($2k).
- One of the co-I's will attend a domestic conference or visit one of the project's modeling partners in each year of the project ($2k).

Procurements - Subcontracts/Subawards

- Subcontract to Caltech for a Post-doctoral Fellow, 100% FTE.
- Chargebacks (calculated at $5.04/labor hour in FY08 dollars.): All JPL desktop computers are subject to a monthly service charge that includes hardware, software, network access, and technical support. ($3.3K).

Procurements - Equipment

- Data storage request is discussed above.

Procurements - Supplies and Publications

- Publication and documentation charges ($5K/yr).
- Computer related software and hardware supplies/upgrades ($3k/yr).

Other Direct and Indirect Costs

See the **JPL Cost Accumulation System**, in Sect 6.2, for a discussion of these costs.

- Multiple Program Support (MPS)
- Allocated Direct Costs (ADC)
- Applied General ADC
- Award Fee